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A TECHNICAL METHOD OF USING THE MERCURY ARC TO OBTAIN DATA AT WAVE LENGTH 560 mμ IN THE SPECTROPHOTOMETRIC ANALYSIS OF SUGAR PRODUCTS [1]

By H. H. Peters [2] and F. P. Phelps

ABSTRACT

From the data on 40 representative cane sugar products it is shown that the specific absorptive index, $-\log \mathbf{t}$, of these products for wave length 560 mμ may be calculated with sufficient exactness for all ordinary purposes by deducting 48 per cent of the difference between the values of $-\log \mathbf{t}_{546}$ and $-\log \mathbf{t}_{578}$ from $-\log \mathbf{t}_{546}$. This interpolation permits the use of the mercury vapor lamp with spectral filters as the source of light for making routine spectrophotometric measurements on technical sugar product, thereby making possible the use of the spectrophotometric method of determining the color of sugar products in many instances where an elaborate spectrophotometer is not available.

It has been shown elsewhere [3] that wave length $\lambda = 560$ mμ acquires a particular importance in the quantitative spectrophotometric analysis of the absorption and transmission spectrum of technical sugar products. Through a simple measurement of absorption or transmission at this wave length it is possible to arrive at a nearly correct estimate of color in relation to the effective quantity of coloring material per gram of saccharine dry substance.

Unfortunately no suitable monochromatic light source of wave length $\lambda = 560$ is known. At present the measurement of absorption or transmission of sugar solutions at this wave length involves the use of a spectrophotometer which in many cases is not available in industrial sugar laboratories. The primary purpose of this paper is to show that the specific absorptive index [4] ($-\log_{10}\mathbf{t}$) of sugar products for wave length 560 mμ may be obtained with sufficient accuracy by interpolation between the $-\log \mathbf{t}$ values for the two mercury wave lengths, 546 and 578 mμ. Figure 1 shows curves for $\mathbf{t}$, $-\log \mathbf{t}$, and Q from $\lambda = 436$ to $\lambda = 700$ mμ for colored sugar products containing unit quantity of coloring material of the various types. *A* is the curve for A sucrose; *6XZ* the curve for 6 samples of soft sugars from

[1] Presented in abstract at the meeting of the American Chemical Society at Baltimore, April, 1925.
[2] Deceased.
[3] B. S. Tech. Paper No. 338.
[4] For the precise definition of the terms and symbols used throughout this paper see footnote 3 above.

localities X and Z; *7XZ* the curve for 7 samples from localities X and Z, etc. *S* is the curve representing the $-\log T$ of a Stammer plate so reduced in thickness that its $-\log T$ at $\lambda = 560$ is 0.000485. It is seen that this curve does not match at all well with any of the types of sugar coloring matters.

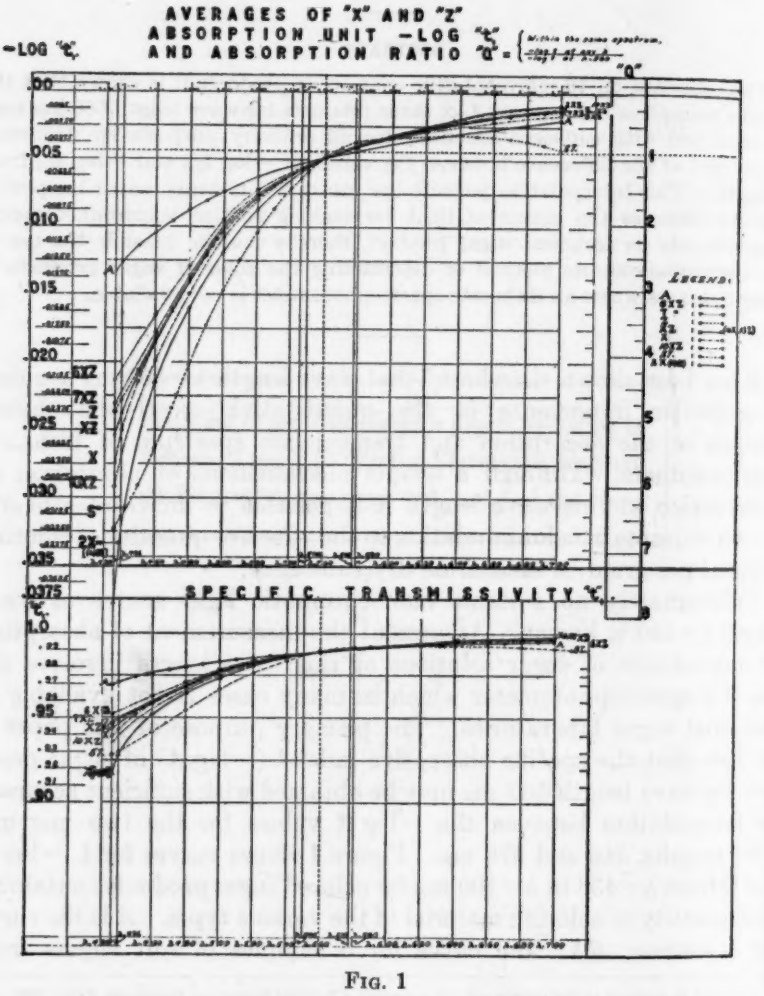

FIG. 1

It will be seen from these curves, which are representative of extreme types of coloring matter found in sugar products, that between the wave lengths 578 and 546 all the curves are very similar. They all are smooth curves with no sudden changes in direction, such, for instance, as occur in the case of dyes, and all slope in the same general direction; indeed, between these two wave lengths the curves are almost straight lines with differing slopes. The similarity is so great

that it would seem possible to obtain the value at 560 with sufficient accuracy for routine work by interpolating between the wave lengths 546 and 578. This would permit the mercury vapor lamp to be used as the light source in connection with one of the less expensive photometers and thereby simplify the problem of obtaining monochromatic light.

Priest and Peters [5] have used the mercury arc together with suitable spectral filters in connection with a Martens photometer for measuring the reflecting power of various substances. Bates [6] and Associates [7] first used the mercury arc together with spectral filters for the measurement of sugar colors in the spectrophotometric analysis of over 200 sugar products, of which approximately 150 were white sugars and the rest soft and raw sugars. The photometer used by the latter workers will be described in a subsequent paper. It was constructed from the well-known Stammer colorimeter by substituting for the Stammer color plates one of two interchangeable rapidly rotating sectored disks whose transmissions were 80 and 46 per cent, respectively. The column of filtrate was varied in length by the plunger until the light transmitted by the solution matched that transmitted by the sectored disk. This was done for each of three mercury wave lengths, the unwanted rays being in each case excluded by suitable color filters over the eyepiece. $-\text{Log } \mathbf{T}$ of the solution was then equal to $-\log T$ of the rotating sectored disk, from which $-\log \mathbf{t}$ could be calculated in the usual manner.

A Hesse-Ives tint photometer also has been used by substituting the mercury light and suitable spectral filters in place of the usual white light source and filters and using plane parallel glass cells of known thickness to hold the solution.

The specifications for spectral filters for use with the mercury arc may be obtained from the data presented by Gibson, Tyndall, and McNicholas in Bureau of Standards Technologic Paper No. 148 (1920), Ultra-violet and Visible Transmission of Various Colored Glasses; and by Gibson, "Spectral filters," J. Opt. Soc. Am. and Rev. Sci. Inst., **13**, p. 275; September, 1926.

As a result of the present investigation the following simple rule,[8] whose validity is predicated upon the prevalence of normal [9] absorption spectra, has been worked out for calculating the color value per gram of saccharine dry substance, or the colorimetric equivalent of $-\log \mathbf{t}$ at $\lambda = 560$, from the measured values at $\lambda = 578$ and $\lambda = 546$.

---

[5] B. S. Tech. Paper No. 92.

[6] B. S. Sci. Paper No. 34.

[7] Comparative analysis of refined sugars, presented before Am. Chem. Soc., at Chicago, Ill., September, 1920. Abstract published in Internat. Sugar J., **22**, p. 654; 1920. Color values of high-grade sugars, presented before Am. Chem. Soc., at Birmingham, Ala., April, 1922. Abstract published in Internat. Sugar J., **24**, p. 296; 1922.

[8] See B. S. Tech. Paper No. 338, pp. 283–284.

[9] Absorption spectra of sugar products are considered normal if the absorption ratios, Q, of the samples in question are similar in magnitude to those here recorded. See p. 339.

Rule: (*a*) Calculate the difference, D (see Table 1, column 6), between $-\log \mathbf{t}$ at $\lambda = 546$ and $-\log \mathbf{t}$ at $\lambda = 578$.

(*b*) Subtract 48 per cent of the difference, D, so found from $-\log \mathbf{t}$ at $\lambda = 546$. This gives within the experimental error the value for $-\log \mathbf{t}$ at $\lambda = 560$ (Table 1, column 9).

(*c*) Convert [10] the $-\log \mathbf{t}$ at $\lambda = 560$ into n color units or n units of coloring matter per gram of saccharine dry substance by means of the equation

$$n = \frac{-\log \mathbf{t}_{560}}{0.00485}$$

The validity of the above rule has been investigated only for concentrated transparent asbestos filtrates, prepared as recommended in Bureau of Standards Technologic Paper No. 338, and not for other solutions.

This rule has been found to hold for practically all of more than 300 spectra. Only 40 of these are presented here and they were selected as representative of typical absorption spectra of cane-sugar products of well-known color characteristics.

Whether the same method of conversion may also be applied safely in the case of beet-sugar products is a matter of conjecture for the reason that not many beet-sugar products were investigated. In the few instances for which it was tested it was found to hold. (See Table 3.)

I. ABSORPTION SPECTRA OF SUGAR PRODUCTS (TABLE 1)

Sections I and II of the table comprise so-called soft sugars as manufactured by two leading refineries which are designated X and Z. Section III consists of three groups of samples from consecutive stations in the refinery. Group III (1) consists of 9 sirups; Group III (2), 4 magmas; and Group III (3), 4 granulated sugars. The products to and from the "A," "B," and "C" pans are identified in the table by the letters (*a* to *d*). (*a*) designates the panfeed, a sirup to be boiled into the magma (*b*); the finished "strike" from this boiling goes to the centrifugals and is there separated into the run-off (*c*) and the granulated sugar (*d*). A run-off (*R. O.*) of a strike of an "A" pan becomes a panfeed (P. F.) to a "B" pan, and so on, the nonsugars and color increasing continuously from the "A" pan to the last run-off or tail-end (5*c*).

The specific absorptive indices, $-\log \mathbf{t}$, at $\lambda = 436$, 546, 578, and 560 mμ of the 40 representative cane sugar products are presented in Table 1, columns 2, 3, 4, and 5. These $-\log \mathbf{t}$'s were measured on a precision spectrophotometer of the Nutting type made by Adam

[10] B. S. Tech. Paper No. 338, p. 267.

Hilger, the light source being a white-lined box (see Bureau of Standards Technologic Paper No. 338, p. 282) instead of the usual light source supplied by the makers.

The differences between the values of $-\log \mathbf{t}$ at 546 and at 578 (D) and between those at 546 and 560 (D_1) are shown in columns 6 and 7. The ratio, $\frac{D_1 \times 100}{D}$ for each sample; that is, the percentage of D which must be deducted from $-\log \mathbf{t}_{546}$ to give the measured value of $-\log \mathbf{t}$ at 560 is given in column 8. When it is considered that relatively large differences in the values in column 8 produce only small differences in the calculated $-\log \mathbf{t}$ values, it will be seen that the values in column 8 are all so nearly the same that the average value of 48 per cent is sufficiently accurate for use in commercial analyses. That this is true may readily be seen by comparing the measured values of $-\log \mathbf{t}_{560}$ in column 5 with the values in column 9, which were calculated from columns 3 and 4, using the factor of 48 per cent. The agreement is further brought out by comparing columns 10 and 11 wherein the $-\log \mathbf{t}$ values have been converted into units of coloring matter per gram of saccharine dry substance. Columns 12 and 13 give the differences between columns 10 and 11. It will be seen from column 13 that the difference seldom exceeds 1 per cent, which is considered to be within the experimental error of the measurements.

The calculation on the basis of 48 per cent is therefore sufficiently exact for all normal types of technical cane sugar products.

The absorption ratios, $Q = \frac{-\log \mathbf{t}_\lambda}{-\log \mathbf{t}_{=560}}$, for $\lambda = 436$, 546, and 578, are given in columns 14, 15, and 16 as an indication of the particular individual type of coloring matter in each sample. The Q ratio for 436 is of the greatest interest for this purpose. That for the other end of the spectrum, about 700 mμ, is next in importance, but, of course, is not obtainable with the mercury light.

Among the Q ratios at 436, soft sugar No. 6X stands out as a rather extreme limit. The Q ratios for all the others are normal in that they are of about the magnitude frequently occurring for each particular grade of product.

The rule given above has been tested and found valid for many other products ranging from white sugar to molasses. Table 2 shows some of these results.

TABLE 1.—*Absorption spectra of sugar products*

I. SOFT SUGARS OF LOCALITY X

Name or designation of product	−Log t (observed)				Difference		$\frac{D_1 \times 100}{D}$	−Log t calculated on the basis $\frac{D_1 \times 100}{D} = 48$	Units of coloring matter per gram of saccharine dry substance		Difference—		The ratio $Q = \frac{-\log t}{-\log t_{560}}$		
					D	D_1			Observed	Calculated	Between columns 10 and 11; units of coloring matter	Between columns 5 and 9 and 10 and 11 expressed in per cent			
	λ=435	λ=546	λ=578	λ=560	λ=546 to λ=578	λ=546 to λ=560							λ=436	λ=546	λ=578
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
							Per cent								
6X	1.040	0.1435	0.0926	0.1200	0.0509	0.0235	46.2	0.1191	24.74	24.56	−0.18	−0.75	8.67	1.20	0.77
7X	1.051	.2013	.1419	.1750	.0594	.0263	44.3	.1728	36.08	35.84	−.24	−1.3	6.01	1.15	.81
8X	1.4657	.2576	.1800	.2120	.0776	.0456	58.8	.2204	43.71	45.44	+1.73	+4.0	6.91	1.22	.85
9X	1.860	.3929	.2731	.3400	.1198	.0529	44.2	.3354	70.10	69.16	−.94	−1.3	5.47	1.16	.80
10X	2.099	.4266	.2932	.364	.1334	.0626	46.9	.3626	75.05	74.76	−.29	−.4	5.77	1.17	.81
11X	3.270	.7799	.5716	.681	.2083	.0989	47.5	.6799	140.4	140.2	−.2	−.2	4.80	1.15	.84
12X	4.146	.9536	.6856	.825	.2680	.1286	48.0	.825	170.1	170.1	0	0	5.03	1.16	.83
13X	4.040	.9032	.6571	.781	.2461	.1222	49.7	.7851	161.0	161.9	+.9	+.5	5.17	1.16	.84
14X	5.334	1.3372	.9939	1.18	.3433	.1572	45.8	1.1724	243.3	241.7	−1.6	−.6	4.52	1.13	.84
15X	6.973	1.878	1.400	1.646	.4780	.2320	48.5	1.6486	339.4	339.9	+.5	+.2	4.24	1.14	.85
II. SOFT SUGARS OF LOCALITY Z															
2Z	0.05776	0.01680	0.01223	0.01450	0.00457	0.00230	50.3	0.01461	2.99	3.01	+0.02	+0.76	3.98	1.16	0.84
3Z	.12463	.03501	.02429	.03000	.01072	.00501	46.7	.02986	6.19	6.16	−.03	−.47	4.15	1.17	.81
4Z	.20628	.05425	.03833	.04700	.01592	.00725	45.5	.04661	9.69	9.61	−.08	−.83	4.39	1.15	.82
6Z	.39762	.08406	.05742	.0715	.02664	.01256	47.1	.07127	14.74	14.70	−.04	−.32	5.56	1.18	.80
7Z	.73187	.15639	.10480	.13100	.05159	.02539	49.2	.13163	27.01	27.14	+.13	+.48	5.59	1.19	.80
8Z	1.1711	.27680	.19409	.2370	.08271	.03980	48.1	.2371	48.87	48.89	+.02	+.04	4.94	1.17	.82
9Z	1.3038	.26642	.18715	.2270	.07927	.03942	49.7	.22837	46.81	47.09	+.28	+.60	5.74	1.17	.82
10Z	1.8571	.38497	.27680	.3335	.10817	.05147	47.6	.33305	68.76	68.67	−.09	−.13	5.57	1.15	.83
11Z	3.1688	.76217	.54536	.6560	.21681	.10617	49.0	.65810	135.3	135.7	+.4	+.32	4.83	1.16	.83
12Z	3.7342	.86256	.64833	.7510	.21423	.11156	52.1	.75973	154.8	156.6	+1.8	+1.16	4.97	1.15	.86
13Z	5.8211	1.2456	.93624	1.090	.30936	.15560	50.3	1.0971	224.7	226.2	+1.5	+.65	5.34	1.14	.86
14Z	7.619	2.0934	1.5616	1.850	.5318	.2434	45.8	1.8381	381.5	379.0	−2.5	−.64	4.12	1.13	.84
15Z	14.7244	3.8908	2.9165	3.400	.9743	.4908	50.4	3.4231	701.0	705.8	+4.8	+.68	4.33	1.14	.86

III. PANFEEDS (P. F.), MAGMAS (M.), RUN-OFFS (R. O.), AND GRANULATED SUGARS (G. S.) FROM A REFINERY

III. PANFEEDS (P. F.), MAGMAS (M.), RUN-OFFS (R. O.), AND GRANULATED SUGARS (G. S.) FROM A REFINERY

III. (1) SIRUPS (PANFEEDS AND RUN-OFFS)

1(*a*). P. F. to "A" pan	0.03939	0.00811	0.00547	0.00690	0.00264	0.00121	45.8	0.00684	1.42	1.41	−0.01	−0.87	5.71	1.18	0.79
1(*c*). R. O. from "A" pan	.13422	.02910	.02081	.02485	.00829	.00425	51.3	.02512	5.12	5.18	+.06	+1.09	5.40	1.17	.84
2. "A" pan liquor	.09816	.02098	.01550	.01830	.00548	.00268	48.9	.01835	3.77	3.78	+.01	+.27	5.36	1.15	.85
3(*a*). No. 2 P. F. to "B" pan	.04178	.00701	.00513	.00615	.00188	.00086	45.7	.00611	1.27	1.26	−.01	−.65	6.79	1.14	.83
3(*c*). R. O. from "B" pan	.37089	.08137	.06094	.07150	.02043	.00987	48.3	.07157	14.74	14.76	+.02	+.10	5.19	1.14	.83
4(*a*). "B" P. F. to "C" pan	.37020	.10011	.07643	.08900	.02368	.01111	46.9	.08874	18.35	18.30	−.05	−.29	4.16	1.12	.86
4(*c*). R. O. from "C"	.80362	.21765	.14861	.18600	.06904	.03165	45.8	.18451	38.35	38.04	−.31	−.80	4.32	1.17	.80
5(*a*). No. 4 P. F. (tailend)	2.2015	.32622	.22825	.27700	.09797	.04922	50.2	.27919	57.11	57.57	+.46	+.79	7.95	1.18	.82
5(*c*). R. O. from tailend	4.3066	.69959	.45556	.5780	.24403	.12159	49.8	.58246	119.2	120.1	+.9	+.77	7.45	1.21	.79

III. (2) MAGMAS

1(*b*). "A" pan	0.07222	0.01893	0.01456	0.01680	0.00437	0.00213	48.7	0.01683	3.47	3.46	−0.01	+0.18	4.30	1.13	0.87
3(*b*). "B" pan	.14846	.03918	.02799	.03400	.01119	.00518	46.3	.03381	7.01	6.97	−.04	−.56	4.37	1.15	.82
4(*b*). "C" pan	.41955	.10840	.07963	.09500	.02877	.01340	46.6	.09459	19.59	19.50	−.09	−.43	4.42	1.14	.84
5(*b*). Tailend	2.1575	.30714	.21548	.26150	.09166	.04564	49.8	.26314	53.92	54.26	+.34	+.63	8.25	1.17	.82

III. (3) GRANULATED SUGARS

1(*d*). From "A" pan	0.01619	0.00641	0.00529	0.00587	0.00112	0.00054	48.2	0.00587	1.21	1.21	0	0	2.76	1.09	0.90
3(*d*). From "B" pan	.02269	.00779	.00643	.00715	.00136	.00064	47.1	.00714	1.47	1.47	0	−.14	3.17	1.09	.90
4(*d*). From "C" pan	.03741	.01081	.00808	.00955	.00273	.00126	46.2	.00950	1.97	1.96	−.01	−.52	3.92	1.13	.85
5(*d*). From tailend	.05832	.01419	.01083	.01265	.00336	.00154	45.8	.01258	2.61	2.59	−.02	−.55	4.61	1.12	.86

TABLE 2

	−Log **t** at 560	
	Observed	Calculated
Cane molasses from a refinery (1926)	20.26	20.31
Cane molasses from a plantation (1920)	11.73	11.75
Java sugar (raw) (1926)	1.49	1.48
Stammer's ulmin solution (diluted)	.378	.379
Caramel (J. S., 1923)	1.517	1.540
Caramel (B_2, 1923)	1.52	1.52
Stammer color plate ($-\log T_{560}$)	.150	.160

The rule apparently holds for many caramelization products and coloring matters produced in part at least by overheating near the steam coils in vacuum pans, etc.

Table 3 gives some data on beet molasses and beet nonsugar. This nonsugar is the desugarized residue of beet molasses, obtained by the barium saccharate process.

TABLE 3.—*The specific absorptive index of beet molasses and beet nonsugar*

λ	−Log **t** of—		"Q" absorption ration of—	
	Beet molasses	Beet nonsugar	Beet molasses	Beet nonsugar
660	0.870	4.35	0.041	0.33
620	1.29	6.97	.61	.53
580	1.77	10.47	.83	.80
578	1.80	10.70	.85	.82
560	2.125	13.12	1.00	1.00
546	2.40	15.40	1.13	1.17
540	2.52	16.52	1.19	1.26
500	3.55	25.68	1.67	2.00
460	5.56	44.59	2.62	3.40
435	8.48	61.15	3.99	4.66

From the data in Table 3 the values for beet molasses are $-\log \mathbf{t}_{560} = \begin{cases} 2.112 \text{ (calculated)} \\ 2.125 \text{ (observed)} \end{cases}$ and for the beet nonsugar $\log \mathbf{t}_{560} = \begin{cases} 13.14 \text{ (calculated)}. \\ 13.12 \text{ (observed)}. \end{cases}$

In the case of these beet sugar products also the rule is seen to hold.

SUMMARY

A rule has been developed for calculating the specific absorptive index ($-\log \mathbf{t}$) of sugar products at wave length $\lambda = 560$ mμ from the values of $-\log \mathbf{t}$ measured at two of the wave lengths obtainable from the mercury vapor lamp. The rule has been tested for a large number of cane-sugar products, including refined sugars, raws, molasses, various intermediate refinery products (panfeeds, run-offs, magmas, etc.), caramelization products, and a few beet sugar products. In practically every instance it was found to hold, since the calculated value seldom differed by more than 1 per cent from the value obtained by actual measurement at $\lambda = 560$ mμ by means of a spectrophotometer.

WASHINGTON, August 3, 1928.

REFLECTING POWER OF BERYLLIUM, CHROMIUM, AND SEVERAL OTHER METALS

By W. W. Coblentz and R. Stair

ABSTRACT

In this paper data are presented on the ultra-violet reflecting power of various metals—beryllium, chromium, cobalt, nickel, silver, speculum, stellite, and stainless steel. For chromium and beryllium the observations extend into the infra-red.

The observations show that contrary to the general experience with other metals, beryllium has a high reflectivity at 250 mμ in the ultra-violet, followed by an appreciably lower reflectivity with a minimum at about 400 mμ in the visible spectrum.

Chromium has a higher reflectivity than nickel in the ultra-violet and is, therefore, the more efficient as a reflector of ultra-violet radiation.

The reflectivity of chromium is conspicuous for its relatively high maximum (70 per cent) at 425 mμ followed by a wide flat minimum which extends from about 600 mμ in the orange to wave lengths beyond 2,000 mμ in the infra-red.

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I. INTRODUCTION

In a previous paper [1] it was shown that a common property of all metals thus far investigated is a low reflecting power in the ultra-violet and in the visible spectrum, followed by a rapid rise in reflecting power, with high values beyond 2,000 mμ, in the infra-red. Subsequent investigations obtained on other material confirm these early deductions. The significance of this phenomenon does not seem to be understood. It is therefore relevant to call attention to the deep minima of reflection previously observed at about 1,000 mμ in zinc, and at about 400 and 700 mμ in beryllium and chromium, respectively, reported upon in the present paper.

[1] Coblentz, B. S. Bull. No. 152, 7, p. 197; 1910.

In recent years it has been found possible to electroplate unusu fine surfaces of chromium upon other metals. The data obtained the present paper were obtained in connection with the questio the reflecting power in the visible spectrum of chromium as compa with nickel, for use as a plating for headlight mirrors. In additio obtaining data to answer this utilitarian question, we have exte our observations into the ultra-violet and the near infra-red, completing the investigation as nearly as can be done at the pre time.

In view of the fact that surfaces of substances, especially me are subject to corrosion, and that ultra-violet light accelerates disintegration of metal surfaces,[2] it is to be emphasized that t data are applicable only to freshly polished surfaces.

While there is no metal surface that can be used indefinitely standard of reflection without frequent repolishing, in the pre paper it is shown that chromium is highly resistant to corrosion has a high reflecting power which extends far into the ultra-vi Chromium should, therefore, prove useful for mirrors and diffrac gratings having a high reflectivity, especially in the ultra-violet.

II. APPARATUS AND PROCEDURE

The measurements recorded in this paper were made spectrora metrically. The radiometer used consisted of a portable vac thermopile,[3] and an ironclad galvanometer [4] of improved de (assembled in 1923) which can be operated in a vacuum, althoug was not used in this manner in the present investigation. measurements in the ultra-violet a shutter of red glass was use eliminate the effect of stray radiation, as described in previous pa

The measurements in the infra-red were made with a comple inclosed spectrometer,[5] which was provided with mirrors 50 c focal length and 10 cm in diameter and a large quartz prism w gave a large dispersion but permitted making observations onl 4,000 mμ.

The measurements in the ultra-violet were made with a qu spectropyrheliometer [6] having plano-convex lenses 6 cm in diam and 18 cm focal length, which was adapted to the present invest tion. For this purpose the focus (also the width) of the entrance was kept constant and, as shown at *V. T.* in Figure 1, the exit (the thermopile slit, 0.8 mm wide) was focused upon the diffe spectral lines. This was facilitated by covering the thermopile

[2] Coblentz and Hughes, Science, **60**, p. 64; B. S. Sci. Paper No. 493, **19**, p. 577; 1924.
[3] Coblentz, B. S. Sci. Papers No. 413, **17**, p. 187; 1921.
[4] Coblentz, B. S. Sci. Papers No. 282, **13**, p. 423; 1916.
[5] Illustrated in B. S. Bull. No. 204, **10**, p. 1; 1913.
[6] Coblentz and Kahler, B. S. Sci. Papers No. 378, **16**, p. 233; 1920.

with a fluorescent screen (white paper saturated with anthracene) which rendered the ultra-violet lines visible to the eye.[7]

The reflecting power in the infra-red was determined by comparing the intensity of the radiation reflected from the unknown sample with that reflected from a metal of known reflecting power.[8] In a previous paper a direct measurement in absolute value was obtained by substituting for the mirror of known reflecting power the hypotenuse face of a right-angle prism,[9] and measuring the intensity of the radiation totally reflected from the glass or quartz prism as indicated at *R. P.* in Figure 1.

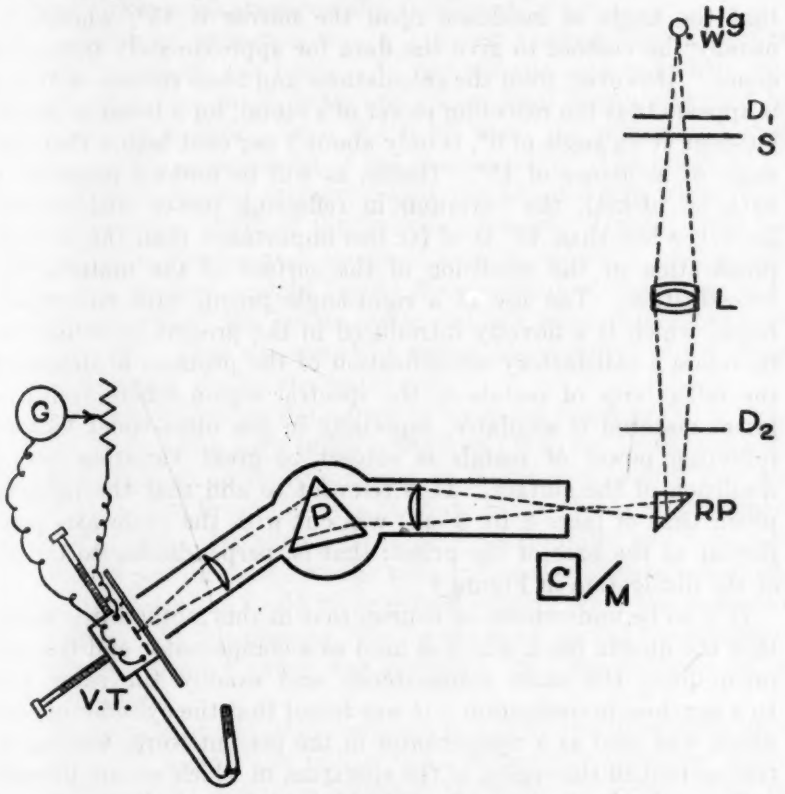

FIG. 1.—*Arrangement of apparatus*

The reflecting power in the ultra-violet was determined directly in absolute value by comparing the intensity of the radiation reflected from the mirror with the intensity of the radiation totally reflected from the right-angle prism of quartz as indicated in Figure 1.

In order to compensate for the lengthening of the optical path introduced by the right-angle prism a plane-parallel piece of the same

[7] Coblentz, J. Opt. Soc. Am., **7**, p. 451; 1923.
[8] Coblentz, B. S. Bull. No. 152, **7**, p. 197; 1911.
[9] Coblentz and Emerson, B. S. Bull. No. 308, **14**, p. 307; 1917.

material (having the same effective thickness as the right-angle prism; *C* in fig. 1) was placed in the path of the rays after reflection from the mirror under investigation. By proceeding in this manner no corrections are necessary for losses by reflection from the faces of the right-angle prism.

We have used the right-angle prism with and without the compensating block in the optical path with the mirror and have found our results in good agreement (within 1 per cent) after making corrections for losses by reflection when the compensating block was not used.

The use of the right-angle prism has the apparent disadvantage that the angle of incidence upon the mirror is 45°, whereas it is usually the custom to give the data for approximately normal incidence. However, from the calculations and observations of Wilsey [10] it appears that the reflecting power of a metal, for a beam of radiation incident at an angle of 0°, is only about 1 per cent higher than for an angle of incidence of 45°. Hence, as will be noticed presently (see data on nickel), the variation in reflecting power with angles of incidence less than 45° is of far less importance than the manner of preparation or the condition of the surface of the material under investigation. The use of a right-angle prism, with compensating block, which is a novelty introduced in the present investigation, is therefore a satisfactory simplification of the problem of determining the reflectivity of metals in the spectral region where transparent prism material is available, especially in the ultra-violet where the reflecting power of metals is subject to great variation with the condition of the surface. It is relevant to add that the right-angle prism (size of faces 3 by 3 cm) was cut with the optic axis perpendicular to the base of the prism; that is, perpendicular to the plane of the illustration in Figure 1.

It is to be understood, of course, that in this method it is assumed that the quartz block which is used as a compensator and the quartz prism have the same transparency and exactly the same polish. In a previous investigation [11] it was found that the cylinder of quartz, which was used as a compensator in the present work, was perfectly transparent in the region of the spectrum in which we are interested.

Owing to the large angle of incidence of the radiation upon the mirror, which increases the polarization, and owing to the further polarization of the rays in passing through the spectroradiometer, the question arises as to the effect this would have upon the reflectivity measurements.

We have, therefore, measured the intensity of the emission line at 365 mμ after reflection at an angle of 45° from a large chromium-plated mirror (*S*, described on a subsequent page) when placed at

[10] Wilsey, Phys. Rev., **8**, p. 396; 1916. Chant, Astrophys. J., **21**, p. 211; 1905, observed practically no variation in the reflecting power of silver for angles of incidence less than 50°.

[11] Coblentz, B. S. Bull. No. 237, **11**, p. 471; 1913.

the exit slit (*V. T.* in fig. 1) so as to reflect the radiation (1) in a horizontal direction and (2) in a vertical direction.

The results obtained show that, to less than 1 part in 200, there was no difference in the intensity of the radiation after reflection in these two positions of the mirror. It is, therefore, assumed that, within the limits of experimental errors, the effects of polarization need not be considered in these measurements.

A slight difference in polish may easily introduce an error of 1 or 2 per cent. This, however, would be a constant error that would not affect the intercomparison of the reflecting power of all the metals, in which problem we are especially interested.

The source of radiation was a 110-volt Cooper-Hewitt vertical "Uviarc" mercury arc lamp. An achromatic quartz-fluorite lens (*L* in fig. 1) 3.5 cm in diameter and 25 cm focal length was used for projecting the radiation from the lamp upon the mirror and from thence upon the entrance slit of the spectrometer. The image of the column of incandescent mercury vapor was about 6 mm wide, which was ten times the width of the spectrometer slit. Hence, there was no difficulty in obtaining an image of uniform intensity over a sufficient width, so that a slight lateral displacement of the image upon the entrance slit of the spectrometer did not produce errors in the measurements. This was tested by actual displacement of the image of the lamp upon the spectrometer slit.

To facilitate adjusting the mirror in the same plane as the hypotenuse face of the right-angle prism a fine wire (*W* in fig. 1) was attached close to the quartz mercury arc, and an image of this wire was projected upon a fine line on a piece of white paper placed at the side of the entrance slit. By tilting the mirror horizontally and vertically the image of certain marks on the wire, reflected alternately from the mirror and the prism, could be projected exactly upon the same spot on the paper. In this manner, exactly the same part of the column of incandescent mercury vapor was projected upon the entrance slit of the spectrometer.

The method of observation consisted in setting the thermopile upon a certain wave length and noting three to five galvanometer deflections produced by radiation reflected (1) from the prism, then (2) from the mirror, after which the measurements on (1) and (2) were repeated. At the completion of the series of measurements throughout the spectrum, further observations at 254 mμ and 265 mμ were made and always found in agreement with the original measurements, showing that the disintegrating effect of ultra-violet light was negligible in the course of the measurements.

Unless otherwise stated, all the surfaces were highly polished and accurately flat to within less than a wave length of light.[12]

[12] Acknowledgment is due E. F. Webb and L. T. Wood for their patience and skill in preparing these mirrors.

III. REFLECTING POWER DATA

Under the present caption are given the spectral reflecting power data, in absolute value, of various metals, including several previously examined.

1. NICKEL

Previous determinations of the reflecting power of nickel were made on mirrors which were electroplated on steel, then polished.[13]

The present measurements were made upon electroplated nickel, also upon pure nickel that had been fused and solidified in a vacuum.[14] The latter appeared to consist of three large crystals. The electroplated samples were deposited upon plates of hardened, highly polished steel. The samples reported upon in this paper were as follows:

I. A highly polished surface of nickel electroplated upon a steel plate 23 by 37 mm in area;

II. A highly polished cross section of a solid rod of pure nickel, 20 mm in diameter, which had been fused and solidified in a vacuum, and

III. A cross section sawed from a rolled rod of refined nickel, 32 mm in diameter.[15] The polish on this sample was not so good as on the other two samples.

The data on the ultra-violet reflecting power of nickel are illustrated in Figure 2. From this illustration it may be noticed that the spectral reflection of the electroplated surface (○○○) is decidedly different from that of the electrolytic material that has been fused and solidified in a vacuum (...). This is substantiated by the measurements of Hagen and Rubens [16] and by Hulburt,[17] whose observations are depicted in Figure 2.

The surface of the rolled rod (###) had a slightly hazy appearance which explains the lower reflecting power. As shown in the upper part of Figure 2, when this sample was examined eight years ago (the surface being highly polished and free from fine granulations) the reflecting power at 550 mμ was 63.5 per cent, which is in agreement with other measurements. Evidently in the recent repolishing of this mirror the fine grinding was not sufficiently prolonged, which left depressions of microscopic size that caused considerable scattering of the light. It is to be emphasized that the inclusion of the data on this sample is to show the presence of the minimum reflection at about 300 mμ in the massive material, which minimum is practically obliterated by the much lower reflecting power at 250 mμ in the electro-

[13] Hagen and Rubens, Ann. der Phys., **1**, p. 352; 1900; **8**, p. 1, 1902; **11**, p. 873; 1903.
[14] Kindly supplied by L. Jordan, of the metallurgy division.
[15] Kindly supplied by Dr. P. D. Merica, the International Nickel Co., Bayonne, N. J.
[16] Hagen and Rubens, Ann. der Phys., **1**, p. 352; 1900.
[17] Hulburt, Astrophys. J., **42**, p. 205; 1915.

lated material. The cause of the relatively much lower reflectivity f the electroplated material at 250 mμ is not known to us.

The curve for the vacuum-fused sample (fig. 2) is the average of ve sets of values obtained with different ajdustments of the mirror, cluding one set of observations which were obtained after further bbing and polishing of the surface on chamois skin moistened with cohol, which, however, had no effect upon the minimum at 300 mμ. Such depressions at 250 to 300 mμ were observed in a previous vestigation of metals and sulphides of metals.[18]

It is relevant to add that the lower reflecting power of the electro-lated material (I) in the visible spectrum is inherent in the sample, d is not owing to the polish such as occurred with the rolled sample

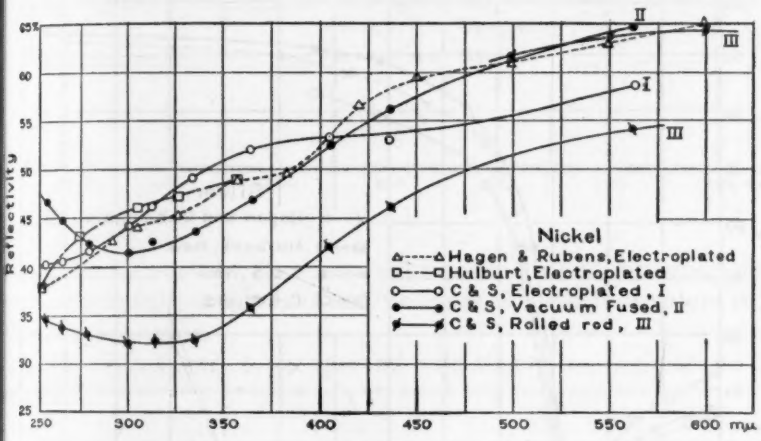

FIG. 2

II). This was evident by observing the sky and leaves of trees flected from these two mirrors. Nevertheless, at 350 mμ in the tra-violet the electroplated sample has the higher reflecting power.

2. SILVER

The ultra-violet measurements were made upon a freshly silvered sur-ce, chemically deposited upon glass. These data (see fig. 3) are in od agreement with previous measurements. The reflecting power of is sample in the blue and the violet is several per cent higher than eviously observed. As mentioned under the preceding caption, is might be owing to a slight difference in the polish of the right-gle prism and the compensating block, which would accentuate the rors in the present instance, although it is not apparent on sub-ances that reflect only 40 to 50 per cent.

[18] Coblentz and Hughes, B. S. Sci. Papers No. 493, **19**, p. 577; 1924.

3. STELLITE

The absolute measurements (in the visible spectrum) are in good agreement with previous data which were obtained by comparison with silver.[19] The value of $R = 66.5$ per cent (67 per cent for normal incidence) at 550 mμ, is slightly lower than previously observed ($R = 68.3$ per cent) which was obtained on the assumption that the reflecting power of the comparison surface of silver was 91.5 per cent. In the meantime the stellite mirror has had considerable use.

This sample of stellite (an alloy of Co, Cr, and Mo) has a minimum at 265 mμ (see fig. 4) while Hulburt (loc. cit.) observed a minimum at 240 mμ on a different sample of this material.

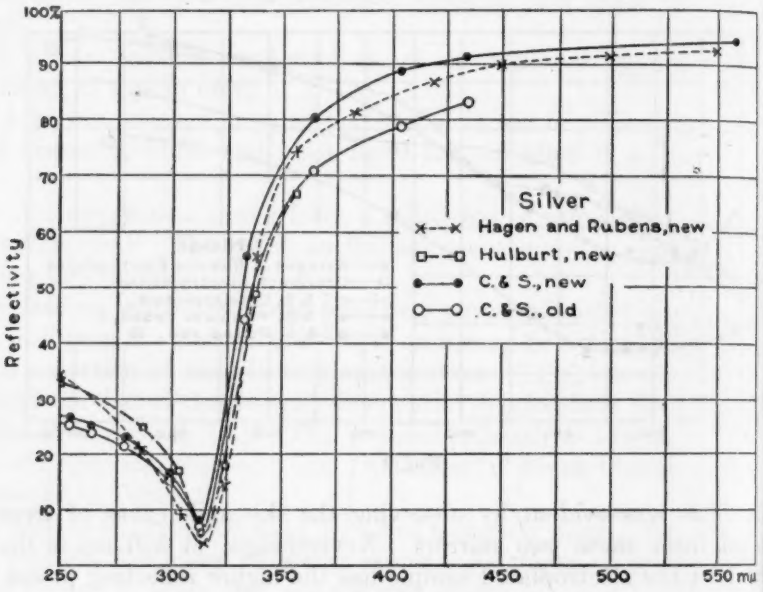

FIG. 3

4. STAINLESS STEEL

The sample examined was reported to contain 13 per cent of chromium but no nickel. The spectral reflecting power in the ultra-violet (fig. 4) is similar to and about 20 per cent higher than that observed by Hagen and Rubens (loc. cit.) on soft steel.

5. SPECULUM

The sample examined was freshly polished to remove the tarnish. The spectral reflecting power (fig. 5) is in fair agreement with the observations of Hulburt (loc. cit.), who gives data showing the rapid decrease in reflectivity with increase in tarnish of this alloy.

[19] Coblentz, B. S. Sci. Papers No. 379, 16, p. 249; 1920.

6. COBALT

The sample examined was in the form of a sheet, about 0.6 mm thick, soldered upon a thick plate of brass. Although it was repolished since the previous measurements [20] were made, it was found

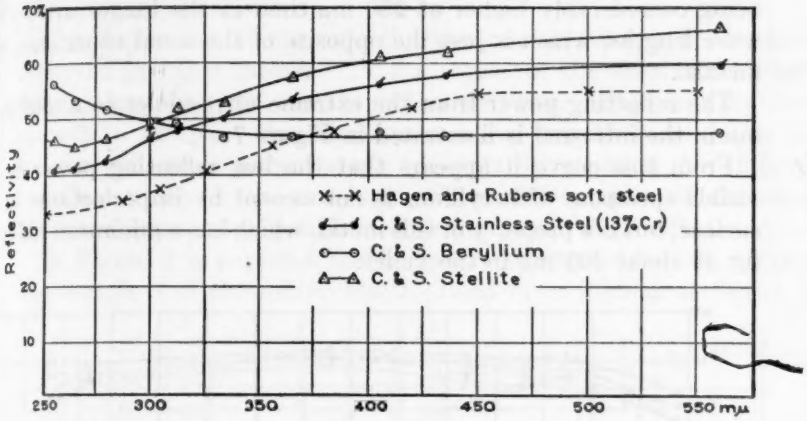

FIG. 4

impossible to remove the hazy appearance caused by microscopic pores which scatter the light and decrease the absolute values in the short wave lengths.

As shown in Figure 5, the spectral reflecting power is similar to that of nickel.

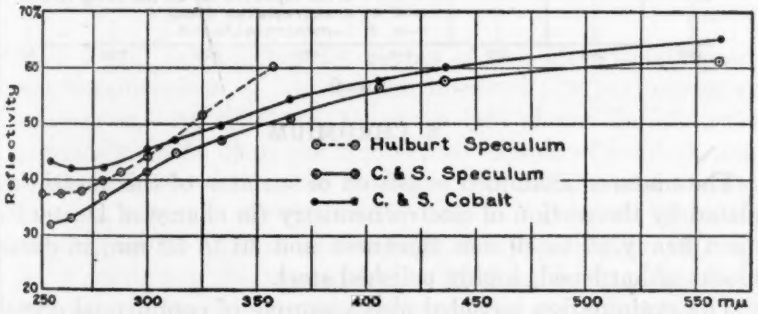

FIG. 5

7. BERYLLIUM

The material examined was obtained from The Beryllium Corporation of America. Chemical analysis indicated the presence of about 1 per cent of Fe, 0.2 per cent of Ba, a trace of Si, and 98.7 per cent of Be.

[20] Coblentz, B. S. Bull. No. 45, 2, p. 457; 1907.

The surface examined was ground and polished upon the flat sid of an ellipsoidal mass of this material which was about 4 cm in i greatest diameter. The polished surface, which was about 25 m in diameter, contained a few scratches and cracks.

The ultra-violet reflecting power of beryllium (fig. 4) is unusual being considerably higher at 250 mμ than in the longer ultra-viol wave lengths, which is just the opposite of the usual experience wi metals.

The reflecting power from the extreme ultra-violet to about 3,0 mμ in the infra-red is illustrated in Figure 7.

From this curve it appears that the low reflecting power in t visible spectrum of beryllium is not caused by imperfections in t surface, but is a property of this metal, which has a minimum reflecti ity at about 400 mμ in the violet.

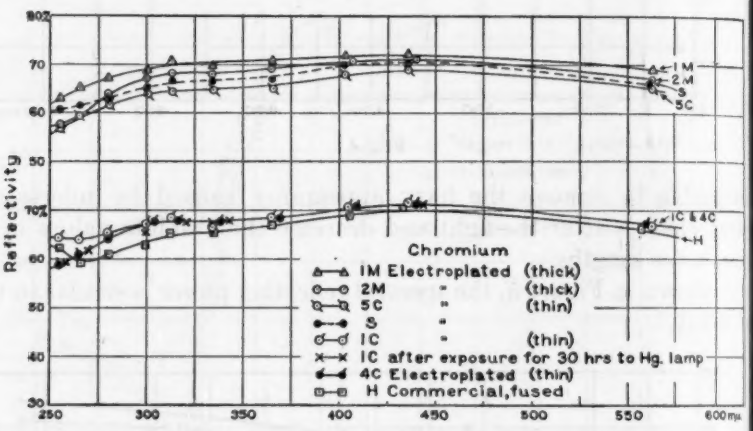

FIG. 6

8. CHROMIUM

The material examined consisted of surfaces of this metal electr plated by the section of electrochemistry (in charge of Doctor Blu upon heavy (5 to 10 mm thickness and 30 to 50 mm in diamet blocks of hardened, highly polished steel.

The examination included also a sample of commercial crystalli material (*H*, fig. 6) upon which the infra-red reflecting power w previously determined.[21] For the recent examination the surfa was highly polished and quite free from the imperfections report in the previous paper, which diffused the incident radiation a lowered the specular reflecting power.

The "thin" coatings of the electroplated material were abo 0.005 mm in thickness. The "thick" coatings were perhaps 0.1 m

[21] Coblentz, B. S. Bull. No. 152, 7, p. 214; 1911.

in thickness. All the samples were optically flat, highly polished, and free from scratches.

There seems to be no direct dependence of the spectral ultra-violet reflecting power upon thickness of the coating, within the above limits. This is illustrated in Figure 6, which gives two groups of reflecting power curves.

The depression in the reflectivity curve at 265 mμ is sometimes observed in other metals. In the region of the spectrum of wave lengths less than 300 mμ the reflecting power seems to vary from sample to sample. For ultra-violet wave lengths longer than 300 mμ the reflecting power seems to be fairly constant for different samples, which is encouraging. All of the samples of chromium examined have a much higher reflecting power than nickel.

In Figure 7 is depicted the composite spectral reflection curve of the sample *S* of chromium, electroplated upon a block of steel 1 by

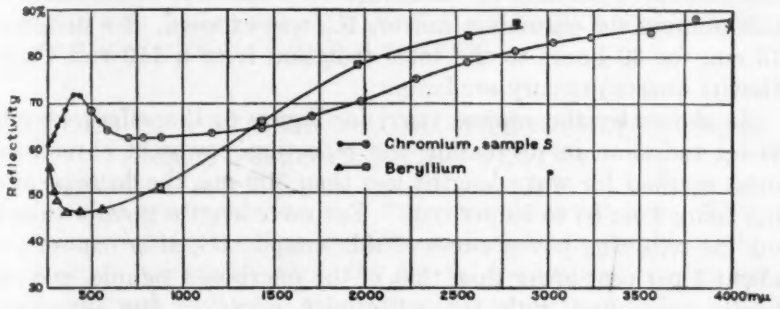

FIG. 7

4 by 5 cm, as observed by means of the ultra-violet quartz lens spectroradiometer (. . .) and the infra-red (○○○) mirror spectroradiometer. At 4,000 mμ the cross (xx) shows the observations [21] previously made upon the commercial sample of solid chromium H which, because of the poor quality of the surface used at that time, gave low values in the short wave lengths. However, from the data obtained in the present investigation it appears that the low reflectivity previously observed at 500 to 2,000 mμ is not owing entirely to scattering of the light by the poorly polished surface, but is a property of the material.

The present investigation shows that a characteristic of chromium is a relatively high reflectivity at about 425 mμ followed by a wide minimum of reflection which extends from about 600 mμ in the orange to wave lengths beyond 2,000 mμ in the infra-red. In this respect chromium appears to be unique. Other metals—for example, silver, gold, and zinc [22]—which have deep minima of reflection (zinc

[21] Coblentz, B. S. Bull. No. 152, **7**, p. 214; 1911.
[22] Coblentz, B. S. Sci. Papers No. 379, **16**, 249; 1920.

at 1,000 mμ) attain a high reflectivity (90 per cent) at 1,500 mμ or even at shorter wave lengths.

From these observations it appears that chromium is more useful than nickel for reflection work in the ultra-violet, but the reverse is true in the spectral region from 600 to 4,000 mμ. However, when one considers the fact that nickel tarnishes readily while a chromium surface is not easily affected, there is probably no great advantage in using nickel as a reflector.

IV. CORROSION BY ULTRA-VIOLET RADIATION

In the introductory part of this paper attention was called to the fact that the ultra-violet reflecting power of metals and sulphides of metals decreases as the result of corrosion or disintegration of the surface by the action of ultra-violet radiation.

It was, therefore, of interest to determine the effect of prolonged exposure of a surface of chromium to ultra-violet radiation. For this purpose the chromium mirror, 1C, was exposed, at a distance of 15 cm, for 30 hours to the total radiation from a 110-volt Cooper-Hewitt quartz mercury arc lamp.

As shown by the crosses (xxx) in Figure 6, the effect of ultra-violet radiation in decreasing the reflecting power of chromium is most marked for wave lengths less than 300 mμ, the decrease at 254 mμ being from 64 to 59 per cent. For wave lengths greater than 300 mμ the reflecting power curve of this sample, 1C, after exposure was about 1 per cent lower than that of the unexposed sample, and practically coincident with the reflectivity curve of the (unexposed) sample 4C.

From this it appears that ultra-violet radiation has but little effect upon the disintegration and consequent lowering of the ultra-violet reflecting power of chromium.

WASHINGTON, October 1, 1928.

NOTE ON A PIEZO-ELECTRIC GENERATOR FOR AUDIO-FREQUENCIES

By August Hund

ABSTRACT

Crystals of quartz can be made to vibrate by electrical means and have been used in this way for some time as standards for the high frequencies used in radio apparatus, which give notes inaudible to the ear. To produce audible frequencies in this way would require a very large crystal. The Bureau of Standards has found that audible frequencies can be produced by using two small crystals which differ slightly in their periods of vibration and furnish a beat or difference in tone which lies within the limits of audibility.

I. METHODS OF OBTAINING AUDIO-FREQUENCIES FROM SMALL PIEZO-ELECTRIC PLATES

Piezo-electric generators for high frequencies are not new. They have been used for some time in radio work and have proved to be quite constant, especially when the crystal holder and circuit are carefully designed and when thermostatic control is provided. To produce audio-frequencies in this way would require a very large crystal. There are several possible arrangements of apparatus which will avoid this difficulty.

(*a*) Two independent generators whose difference in frequency produces an audible note.

(*b*) When two piezo-electric plates are connected in one and the same tube circuit it is possible to produce audio-frequencies. For this purpose the two crystals are best connected in parallel across the grid and filament of the tube.

(*c*) A single piezo-electric crystal with a minute step in it will produce audio-frequencies directly.

(*d*) A crystal cut at a slight angle to the electric axis will produce audio-frequencies directly.

(*e*) A crystal whose dimensions are such that a harmonic of one of the three possible fundamental oscillations beating with one of the other two fundamentals gives audio-frequencies directly.

In all cases it is to be noted that the percentage error in the beat frequency is as many times the error in one of the two high frequencies

as the beat frequency is contained in the average value of the two beating frequencies. This is an inherent disadvantage of the method.

Experiments carried on over a period of several years showed that the schemes under (*a*) and (*c*) are the most promising when audio-frequency standards are concerned. It has been found that a stepped crystal (*c*) with an air gap of about one-third of a millimeter between it and the electrode above it can be held constant in frequency to within a few parts in 100,000, provided the crystal remains fixed in position. If the crystal is moved around in the holder, its frequency may vary as much as one-tenth of 1 per cent.

II. CIRCUIT FOR AUDIO-FREQUENCIES

When using the system described under (*a*) it was found that the effect of the crystal holder was very pronounced. When an air gap was used it was found that the supersonic sound waves reacted back upon the crystal. In addition, the capacity due to the crystal holder had an effect on the frequency. The same is true when a condenser is employed across the inductance in the anode branch of the tube. The setting of the condenser changed the beat frequency especially when the impedance in the anode branch was close to current resonance. All these effects seem much more pronounced than the effect due to normal changes in the temperature, since the temperature effect on the beat frequency is about the same as on each of the two high frequencies because the physical dimensions of the two quartz plates are practically identical.

The arrangement of Figure 1 was finally adopted, and the complete apparatus is shown in Figure 2. It consists of two self-contained independent piezo-electric generators of frequencies f_1 and f_2, respectively. The plate of each circuit is connected through a small air condenser of negligible leakance (special construction) to only one output terminal. The output terminals of the two generators are connected to a radio-frequency amplifier whose reaction is negligible, since a shield grid tube is employed. The audio-frequency current is taken off on the secondary terminals of the transformer in the detector circuit. Since the energy (power) taken away from the two high-frequency sources is very small, a variable condenser is provided across the input coil of the detector. By means of it a tuning to frequencies f_1 and f_2 is possible.

With this arrangement, using circular quartz disks which are sputtered on each side with platinum and whose upper contact (to grid) was made by means of a thin gold leaf pasted at a fixed place, an accuracy of a few parts in 100,000 is obtained.

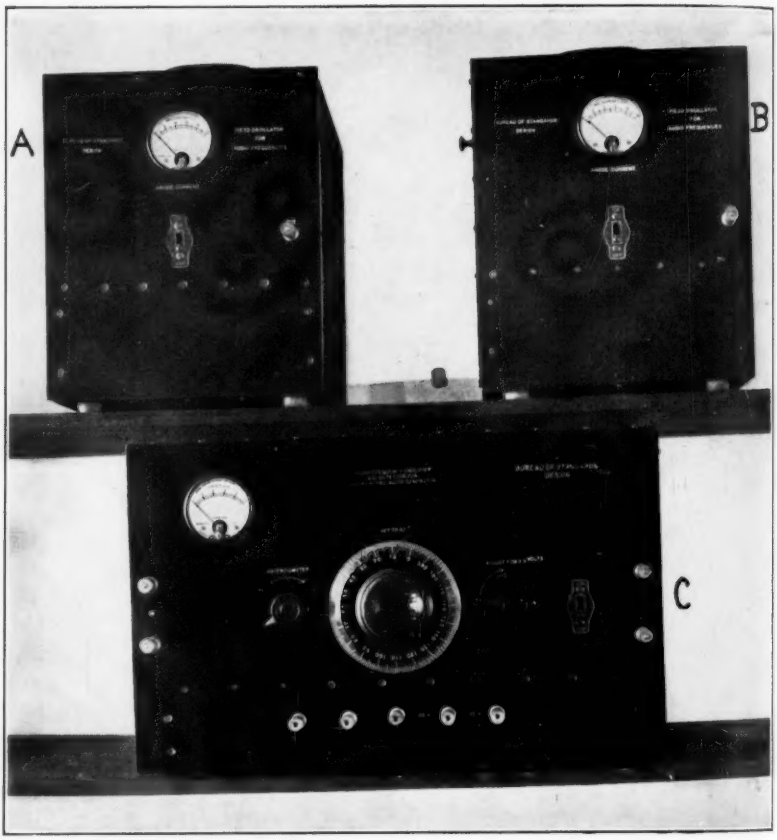

FIG. 2.—*Laboratory apparatus corresponding to Figure 1*

A, Piezo-oscillator of radio-frequency f_1
B, Piezo-oscillator of radio-frequency f_2
C, Radio-frequency amplifier and detector for producing the audio current of frequency f_1-f_2

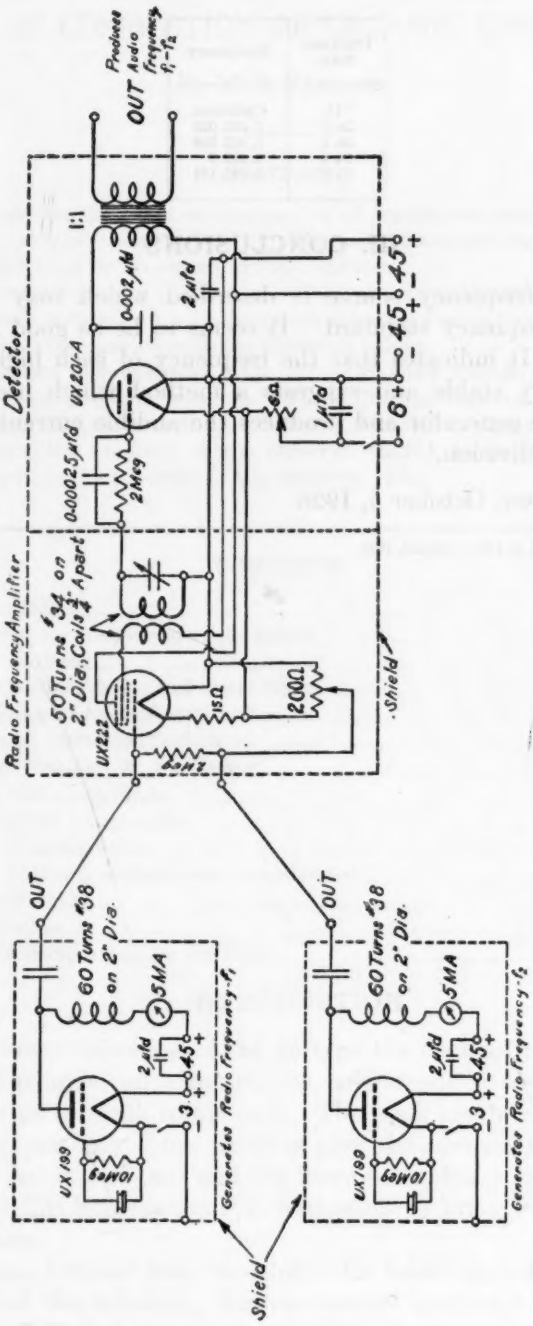

FIG. 1.—*Diagram of connections for the beat oscillator*

A typical test carried out on different days is as follows:

Temperature	Frequency
°C.	*Cycles/sec.*
24.5	1,242.026
24.5	1,242.088
24.5	1,242.1
25.0	1,242.124

III. CONCLUSIONS

An audio-frequency source is described which may serve as a secondary frequency standard. It seems to be as good as a tuning fork drive. It indicates that the frequency of each high frequency must be very stable and suggests a method which uses only one piezo-electric generator and produces the audible current by means of harmonic division.[1]

WASHINGTON, October 5, 1928.

[1] Proc. I. R. E., 16, p. 1072; August, 1928.

HEATS OF COMBUSTION OF ORGANIC COMPOUNDS

By M. S. Kharasch

ABSTRACT

The literature on the heats of combustion of organic compounds is critically reviewed. A table of "best" values for this constant has been compiled covering all available information on record in the literature.

A method for calculating the heat of combustion from the structural formula of the compound is described, and the values calculated according to this method are tabulated for comparison with the observed values.

The comparison demonstrates that the calculated values are sufficiently accurate for most practical purposes. The difference between calculated and observed values seldom exceeds 1 to 2 per cent except in cases where there is reason to doubt the accuracy of the observed value. In most cases the two values agree within the accuracy of the observed value.

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I. INTRODUCTION

In the present collection of the data on the heats of combustion of organic compounds, an attempt has been made to select the best available value for each compound. The work has been particularly difficult because only a few authors give the necessary information concerning the unit of heat and the thermochemical corrections used, and without this information it is impossible to bring the values to a common basis.

The thermochemical data recorded in the tables have been obtained by the use of the following thermochemical methods: (1) The universal-burner method, (2) the bomb method.

The "universal-burner" method, in the hands of Thomsen, gave results which agreed on the average to not better than 0.5 per cent. Owing to the design of his apparatus, it is applicable only to gases or to substances easily volatile at room temperature, and his values are to be trusted only to the extent to which this condition was realized. This seems to be the consensus of opinion of most workers in thermochemistry. It is, however, necessary to apply two corrections to his values in order to bring them into accord with modern determinations. Both of these corrections are negative. The first one (−0.3 per cent) corrects his thermometer readings to the hydrogen scale, and the second one (−0.1 per cent) corrects for the new determinations of the heat capacity of water. Only the values so corrected are recorded in the tables.

The "bomb-calorimeter" method was first used by Andrews [1] in 1848, the determinations being carried out at a pressure of one atmosphere. In 1883 Berthelot reintroduced the method and improved it considerably. The combustions by this improved method were carried out with oxygen under pressure. The details of the technic have since undergone revolutionary revisions. For particulars the reader is referred to the articles of Richards and his collaborators; Roth and collaborators; Dickinson, Verkade, and collaborators; and Swietoslawski and collaborators.

Of the four different procedures that have been proposed for the measurement of heats of combustion by means of a calorimetric bomb, only two have attained considerable use.[2] These are known as the "ordinary" or "common" method and the "adiabatic" method. In the "common" method the rise of temperature of the calorimeter is observed while the "jacket" temperature is kept constant. In the "adiabatic" method the temperature of the "jacket" is kept the same as the temperature of the calorimeter and only the initial and final temperatures measured. This latter method may be called the "American adiabatic" method, for it was first proposed by S. W. Holman [3] and refined thoroughly by Richards and his collaborators. It has been used extensively only in the United States.

It should be stated at this point that the results of the two methods agree within the limits of experimental error.[4]

[1] Andrews, Pogg. Ann., 75, p. 27; 1848.

[2] The other two methods are those of Hosehus and Fery.

[3] S. W. Holman, Proc. Am. Acad., 31, p. 252; 1895.

[4] Dickinson, Bull. Bureau of Standards, 11, p. 243; 1915; Schläpfer and Fioroni, Helv. chim. Acta, 6, p. 725; 1923.

The method of calibrating the calorimetric system is of the greatest importance.[5] The methods which have been at times employed by the investigators and pertain to the values recorded are as follows: (1) Calibration by the electrical method; (2) thermal calibration; (3) the additive calibration.

1. The electrical calibration consists in supplying electrically a measured amount of energy to the calorimeter and measuring the temperature rise. The results of such observations give directly the heat capacity of the calorimeter and its contents in joules per degree. The value in calories is then obtained by dividing by the mechanical equivalent of heat. This method forms the basis of the work of Fischer and Wrede; Wrede, Jaeger, and von Steinwehr; Dickinson, Roth, Swartz, Moureu, and André. The work of these investigators is very thorough and of a high order of accuracy.

2. In the thermal method of calibration a standard substance of known heat of combustion is burned in the calorimeter. Where the other calorimetric measurements have been properly carried out this method, using one of the standard substances mentioned below, yields reliable results.

3. In the additive-calibration method the heat capacity of the calorimeter is obtained by adding together the heat capacities of its parts. This method has been used extensively by some French and some Russian investigators. While the work has been carried out with a great deal of zeal, yet essential details of procedure are often entirely lacking and it is thus usually impossible to compare the values with those of other workers. These statements apply to work of Berthelot and his collaborators, Louguinine, Zubov, and a number of other investigators. Recently the values of Zubov's work have been put upon a better basis by Swietoslawski, to whom Zubov turned over most of his experimental material. From the method

[5] The following are some of the most important references dealing with the calibration of the calorimetric system:

1. Bestimmung des Wasserwertes eines Berthelot'schen Kalorimeter in elektrischen Einheiten, W. Jaeger und H. von Steinwehr, Verhandl. Deutsch. Phys. Ges., **5**, p. 50; 1903; and **5**, p. 353; 1903.

2. Concerning the adiabatic determination of the heat of combusion of organic substances, Richards, Henderson and Frevert, Proc. Am. Acad., **42**, p. 573; 1907.

3. Beitrag zur kalorimetrischen Messung von Verbrennungswärme, W. Jaeger and H. von Steinwehr, Zs. f. Phys. Chem., **53**, p. 153; 1905.

4. Eichung eines Berthelot'schen Verbrennungskalorimeters in elektrischen Einheiten mittels des Platinthermometers, W. Jaeger and H. von Steinwehr, Ann. d. Phys. (4), **21**, p. 23; 1906.

5. Ueber die Korrektur für die Wärmestrahlung bei Kalorimetrischen Versuchen, A. Schukarew, Zs. f. Phys. Chem., **56**, p. 453; 1906.

6. An accurate Calorimeter, White, Phys. Rev., **25**, p. 137; 1907.

7. Eichung des Verbrennungskalorimeter und Arbeitsweise, Roth, Lieb. Ann., **373**, p. 249; 1910.

8. Lag effect and other errors of calorimetry, White, Phys. Rev., **31**, p. 562; 1910.

9. A calorimetric arrangement for the new bomb, Phillippe Landrieu, Bull. Soc. Chim., **37**, p. 1340; 1925.

employed by Swietoslawski in correcting Zubov's data, it is evident that Zubov applied most thermometric corrections, except that the heat capacity of his calorimetric system has been erroneously determined. These recalculated values of Zubov are in better agreement with more modern values and are the ones recorded in the tables.

II. STANDARDS FOR COMBUSTION CALORIMETRY

Of the three substances which have been used in the past as standards in combustion calorimetry, only one has been shown by recent researches to meet the requirements of a primary standard. At the third conference of the International Union of Pure and Applied Chemistry held at Lyons,[6] benzoic acid was adopted as the primary standard. The value chosen for its heat of combustion was the one found by Dickinson,[7] namely, 6,324 g-cal$_{15}$ per gram in air or 6,319 g-cal$_{15}$ per gram in vacuo.[8] It is more or less tacitly assumed that the above value holds for an isothermal heat of combustion in the neighborhood of 20°.[9] When converted into absolute joules these values become 26,466 and 26,445, respectively. Dickinson's value was obtained by absolute electrical standardization of his calorimetric system, and the measurements were carried out by the ordinary as well as the adiabatic method.

It is of importance to note here the determinations which have been made of the ratios of the heats of combustion of benzoic acid, naphthalene, and cane sugar. For these determinations Richards and his collaborators employed only the adiabatic method, Verkade and his collaborators the ordinary method, while Swietoslawski and his collaborators and Schläpfer and Fioroni employed both the adiabatic and ordinary methods. These ratios, as summed up by Schläpfer and Fioroni as a result of a very thorough investigation both by the ordinary and the adiabatic methods, are:

$$\frac{\text{Naphthalene}}{\text{Benzoic acid}} = 1.5201 \text{ (air)} \qquad \frac{\text{Benzoic acid}}{\text{Sucrose}} = 1.6028 \text{ (air)} \qquad \frac{\text{Naphthalene}}{\text{Sucrose}} = 2.4364 \text{ (air)}$$

These ratios are quite similar to those obtained by Dickinson and by Verkade and Coops, jr.[10]

SECONDARY STANDARDS.—Recently Verkade and Coops, jr.[11] have suggested salicylic acid as a secondary standard. Their suggestion, backed by a large amount of information, certainly merits considera-

[6] Germany was not represented at that conference.

[7] Bull. Bur. of Standards, **11**, p. 243; 1915.

[8] See W. Swietoslawski's defense of this value, J. Chim. Phys., **22**, p. 583; 1925; and P. E. Verkade and J. Coops, Z. Physik. Chem., **118**, p. 123; 1925.

[9] See Rec. Trav. Chim., **44**, p. 800; 1925, for the temperature coefficient of the heats of combustion of benzoic and salicylic acids.

[10] P. E. Verkade and Coops, jr., Rec. Trav. Chim., **42**, p. 223; 1923.

[11] P. E. Verkade and Coops, jr., Rec. Tr. Chim., **43**, p. 561; 1924. Note also the discussion by Swietoslawski upon the establishment of such a secondary standard, Bull. Soc. Chim. (4), **37**, p. 84; 1925.

tion. The value for salicylic acid recommended by these investigators is 5,242 g-cal$_{15}$ per gram in air and 5,238 g-cal$_{15}$ per gram in vacuo, that is, $5,242 \times 4.185 = 22,699$ and $5,238 \times 4.185 = 21,921$ absolute joules, respectively.

III. CHOICE OF DATA

Since in the tables below only one value is as a rule given for each compound, it has been necessary to exercise a certain amount of arbitrariness in the choice, but whenever possible the opinions of all workers in thermochemistry, as expressed in their articles, have been taken into account. Naturally, where an author has described carefully his method of procedure, corrections used, etc., or where his method has been sufficiently well established, his values were given preference over those of an author who merely recorded the heats of combustion obtained. The names of all the investigators who have determined the heats of combustion of each compound are, however, recorded. When only one value for a compound is quoted, irrespective of whether or not the value is very reliable, it has been thought desirable to make available even this approximate result. On the whole, for the guidance of the users of the tables, it may be stated that the work of many of the French investigators is not in complete agreement with the best modern determinations. The values are on the whole rather high, but no factor can be employed to correct them, for the variations from author to author are too large. However, the maximum error in most cases is not larger than from 1 to 1.5 per cent.

Preference has been given also to Thomsen's values for gases and for easily volatile compounds over those of Berthelot and his collaborators. The order, however, was reversed for difficultly volatile substances, for Thomsen's values for such compounds are too high.

IV. ABBREVIATIONS, UNITS, AND CONVENTIONS

Unit Employed.—The heats of combustion recorded are expressed in absolute kilojoules (at constant pressure) per gram molecular weight of substance in vacuo. Where the investigators indicated the unit of heat employed by them that unit of heat was multiplied by the proper factor to convert the value into absolute kilojoules, otherwise the 18° calorie was assumed to have been used.[12]

Vacuum Correction.—The vacuum correction in very few cases amounts to more than 0.13 to 0.16 per cent. It is quite evident, therefore, that where the accuracy of the method, experimental procedure, and corrections used apparently introduced a much larger error, such a correction is of very little consequence as far as the

[12] The factors used to convert into joules were the ones adopted by the International Critical Tables.

accuracy of the absolute value is concerned. However, it was felt desirable to bring the values to a common basis, and for that reason the values of the investigators have been corrected *ad vacuum* whenever there seemed the slightest justification for it and when the specific gravity of the substances was known. Of the investigators who have done considerable work in thermochemistry and whose results were sufficiently accurate to merit this correction, we might mention Stohmann and collaborators; Zubov,[13] Roth, Fischer and Wrede; Wrede, Dickinson, Richards and collaborators; Swietoslawski and collaborators; Verkade and collaborators, and a few others. Of course, some of these investigators have themselves applied the correction and record their result upon the basis of weight *in vacuo*.

PHYSICAL STATE.—Unless otherwise specified (by g=gas, v=vapor, s=solid), the values recorded refer to the combustion of the substance in the liquid state, the final products of combustion being gaseous carbon dioxide, liquid water, and nitrogen gas, for C, H, N compounds. In the case of compounds containing other elements consult the discussion under the individual headings.

V. CALCULATION OF HEAT OF COMBUSTION

The calculated values recorded in the tables refer to the heat of combustion of the substance in the liquid state. Whenever, therefore, the heat of combustion of a solid substance is recorded, it is necessary, for the purpose of comparison, to convert that value to the liquid basis. In making that conversion it is necessary, for precision work, to know the molecular heat of fusion referred to 18° C. However, no error of any magnitude is introduced into the calculation of the heat of combustion of a liquid substance by merely subtracting the value of the molecular heat of fusion at the melting point from the heat of combustion in the solid state.

The general basis of calculating heats of combustion is discussed in the paper of Kharasch and Sher.[14] Since the publication of this paper a great deal of experimental work has been carried out by the writer and various collaborators, which enables us to elucidate more fully the general formulas employed. This will be done in papers which will appear elsewhere. To conserve space, factors used will be discussed very briefly, and the user of the table is invited to consult the original papers for the theoretical background and postulates.

It is assumed that, whenever an organic substance is burned in oxygen, the heat generated is due to the interdisplacement of the electrons between the carbon and oxygen atoms. It is assumed, also, that the net amount of these energy interchanges in the form of heat

[13] The corrected values given by Swietoslawski (loc. cit.).
[14] J. Phys. Chem., **29**, pp. 625 to 658; 1925.

is equal to 26.05 kg-cal$_{15}$ per electron per mole, if the initial and final stages correspond to the arrangement the electron occupies around the carbon nucleus in methane and in carbon dioxide, respectively.

It is easy to perceive, therefore, that since the factor 26.05 corresponds only to certain definite initial and final stages of the electron, whenever a substance is burned which contains some electrons displaced from that position the calculated value should be either smaller or larger than the experimental value, depending upon whether the electrons are nearer or farther from the carbon nucleus than those of our reference position; that is, the arrangement of electrons around the carbon nucelus in methane.

In the case of carbon compounds it is assumed that a sharing of electrons may exist, as represented below. The lines merely indicate the distance which the electrons forming the bond may occupy with respect to the two carbon nuclei A and B.

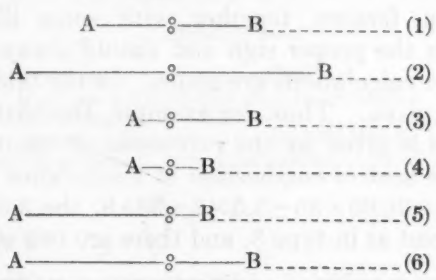


FIG. 1.

Furthermore, if (1) denotes the arrangement of the pair of electrons linking the carbon nuclei in ethane and the expression for the heat of combustion of that compound is $Q=26.05\times N$, where N denotes the number of electrons, then it is self-evident that if (2), (3), (4), (5), and (6) differ from ethane only in the arrangement of one pair of electrons, then the expression for the heat of combustion of these compounds should be:

(1) $Q=26.05\times N$
(2) $Q=26.05\times N+a$
(3) $Q=26.05\times N-b$
(4) $Q=26.05\times N-c$, where c is larger than b.
(5) $Q=26.05\times N+d-e$
(6) $Q=26.05\times N+f$

Bonds of the type (5) and (6) need not be considered here, for (6) is merely a special case of (2) and in (5) the two factors ordinarily cancel one another.

The four distinct types of bonds may be illustrated by a consideration of the following molecules:

1. *Bond of type 1.*—Aliphatic hydrocarbons, ethane as a representative compound.

2. *Bond of type 2.*—A carbon-to-carbon linkage in which both groups are weakly electronegative, such as a COOH next to COOH as in oxalic acid or C=O next to COOH as in $CH_3.CO.COOH$ or two triphenylmethyl nuclei $(C_6H_5)_3.C:C(C_6H_5)_3$.

3. A bond between a carbon of an aliphatic radical or any other C-atom and a carbon atom of a strongly electronegative radical such as phenyl;[15] thus, $C_6H_5.CH_3$.

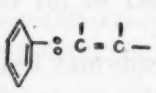
4. A bond between two carbon atoms of two strongly electronegative radicals, such as $C_6H_5.C_6H_5$, naphthalene, anthracene, etc.

We have thus a general expression for the heat of combustion of organic compounds, $Q=26.05\times N$ plus certain correction factors for those electrons that are displaced from the reference position, the sign of the correction factor indicating, except in the case of carbon-oxygen bonds, whether the electrons are displaced *away* from the nucleus of the carbon atoms or *toward* the nucleus.

The correction factors, together with some illustrations, are given below with the proper sign and should always be taken into account whenever calculations are made. In the table only the type formulas will be given. Thus, for example, the heat of combustion of aromatic acids is given by the expression $Q=26.05\times N-3.5$, but in calculating the heat of combustion of a substance such as *o*-toluic acid, we have $Q=26.05\times 36-3.5\times 2=930.8$, the 3.5 being the correction for the bond as in type 3, and there are two such bonds.

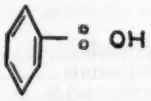
VI. STRUCTURAL CORRECTION FACTORS

Symbol	Pair of electrons held between—	For each such grouping add or subtract as indicated
a	Aromatic radical ⋮ Aliphatic radical	−3.5
	Examples:	
	1. Mesitylene $Q=26.05\times 48-3\times 3.5=1239.9$.	
	2. Tertiary butylbenzene $Q=26.05\times 54-3.5=1403.2$.	
b	Aromatic radical ⋮ Aromatic radical	−6.5
	Examples:	
	1. Naphthalene $Q=26.05\times 48-6.5\times 2=1233.4$.	
	2. Diphenyl $Q=26.05\times 58-6.5=1497.9$.	
c	Ethylene bond $-\overset{|}{C}=\overset{|}{C}-$	+13.0
	Examples:	
	1. Trimethylethylene $Q=26.05\times 30+13=794.5$.	
	2. Diamylene $Q=26.05\times 60+13=1576.0$.	

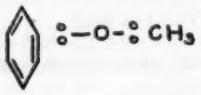


[15] Consult paper of Kharasch and Marker, J. A. C. S., 48, p. 3130; 1926, for a table of relative electronegativity of organic radicals, and also Kharasch and Flenner (to be published).

VI. STRUCTURAL CORRECTION FACTORS—Continued

Symbol	Pair of electrons held between—	For each such grouping add or subtract as indicated
d	Aromatic radical carbon ⋮ Vinyl radical Example: Styrene $Q=26.05\times40+13-6.5=1048.5$.	−6.5
e	Ethylene bond in ring system, as in cyclohexene	+6.5
	 Examples: 1. Tetrahydrobenzene $Q=26.05\times34+6.5=892.2$. 2. Methyl-1-cyclohexene-1 $Q=26.05\times40+6.5=1048.5$.	
	Acetylene bond	
g	One or more replaceable hydrogens—C≡C— Example: Heptine-1 $Q=26.05\times40+46.1=1088.1$.	+46.1
h	No replaceable hydrogens R—C≡C—R Example: Dimethyl diacetylene $Q=26.05\times30+33.1\times2=847.7$.	+33.1
i	Aromatic radical carbon ⋮ Acetylene radical Example: Phenyl ethine $Q=26.05\times38+46.1-6.5=1029.5$.	−6.5
	Alcohols	
j	Aliphatic radical ⋮ Hydroxyl group (Primary alcohol) Example: Methyl alcohol $Q=26.05\times6+13=169.3$.	+13.0
k	Secondary radical ⋮ Hydroxyl group (Secondary alcohol) Examples: 1. Cyclohexanol $Q=26.05\times34+6.5=892.7$. 2. Amyl phenyl propargyl alcohol $Q=26.05\times72+33.1+6.5-3.5=1911.7$.	+6.5
l	Tertiary radical ⋮ Hydroxyl group (Tertiary alcohol) Examples: 1. Methyl diethyl carbinol $Q=26.05\times36+3.5=941.3$. 2. Diphenyl phenyl ethinyl carbinol. $Q=26.05\times98+33.1+3.5-6.5-3.5.2=2576.0$.	+3.5
m	Aromatic radical ⋮ Hydroxyl group  Examples: 1. *m*—Cresol $Q=26.05\times34+3.5-3.5=885.7$. 2. Thymohydroquinol $Q=26.05\times50+3.5\times2-3.5\times2=1302.5$.	+3.5
o	Acetal linkage $R.C\overset{H}{\vdots}-(O-R_1)_2$ where R and R_1 are aliphatic radicals. Examples: 1. Glycol acetal $Q=26.05\times20+19.5\times2=560.1$. 2. Dipropyl methylal $Q=26.05\times40+19.5\times2=1081.1$.	+19.5

VI. STRUCTURAL CORRECTION FACTORS—Continued

Symbol	Pair of electrons held between—	For each such grouping add or subtract as indicated
p	Aromatic ethers 	+19.5

Examples:
1. *m*-Cresol methyl ether.
$Q=26.05\times40+19.5-3.5=1058.5.$
2. Resorcinol dimethyl ether.
$Q=26.05\times38+19.5\times2=1028.9.$

q	Aliphatic aldehydes $R-\overset{H}{C}=O$	+13.0

Example: Acetaldehyde $Q=26.05\times10+13.0=273.5.$

r	Aromatic aldehydes $R.\overset{H}{C}=O$	+13.0

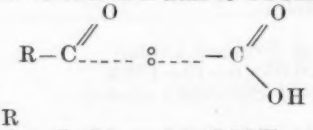
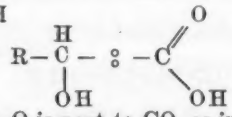
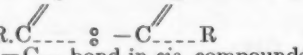
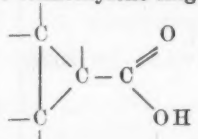
Example: *p*-Hydroxybenzaldehyde.
$Q=26.05\times30+13.0-3.5+3.5=794.5.$

s	Aliphatic ketones $R-\overset{O}{\overset{\|\|}{C}}-R$	+6.5

Examples:
1. Methyl propyl ketone.
$Q=26.05\times28+6.5=735.6.$
2. Allylacetone $Q=26.05\times32+6.5+13.0=866.1.$

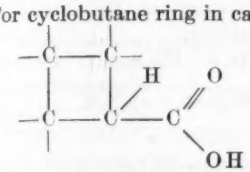
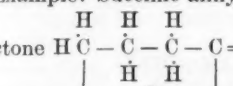
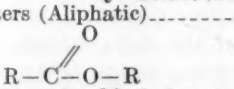
t	Aromatic ketones $R-\overset{O}{\overset{\|\|}{C}}-C_6H_5.$	+6.5

Example: Benzophenone $Q=26.05\times60+6.5-3.5\times2=1562.5.$

u	If $R-C=O$ radical is next to COOH radical, as in 	+13
v	If $R-\overset{R}{\underset{OH}{\overset{\|}{\underset{\|}{C}}}}$ radical is next to COOH, as in 	+6.5
w	If $R-C=O$ is next to CO, as in 	+6.5
x	For $-C=C-$ bond in *cis* compounds	+16.5
y	For $-C=C-$ bond in *trans* compounds	+13.0
z	For trimethylene ring in carboxylic acids, as in 	+13.0

Example: Trimethylenecarboxylic acid.
$Q=26.05\times18+13=481.9.$

VI. STRUCTURAL CORRECTION FACTORS—Continued

Symbol	Pair of electrons held between—	For each such grouping add or subtract as indicated
aa	For cyclobutane ring in carboxylic acids	+13.0
		
	Example: Tetramethylenedicarboxylic acid. $Q=26.05\times24+13=638.2$.	
bb	Acid anhydride $R.C(=O)-O-C(=O)-R$	+10.0
	Example: Succinic anhydride $Q=26.05\times14+10=374.3$.	
cc	Lactone 	+13.0
	Example: Saccharic acid lactone. $Q=26.05\times24+13+3.5+6.5+13.0=662.2$.	
dd	Esters (Aliphatic) 	+16.5
	Example: Methyl acetate $Q=26.05\times14+13=381.2$.	
ee	Aliphatic radical : NH_2	+13.0
	(Primary aliphatic amine)	
	Example: Propyl amine $Q=26.05\times21+13=560.1$.	
ff	Aliphatic radical : N(H) : —Aliphatic radical	+19.5
	(Secondary aliphatic amine)	
	Example: Benzylethylamine $Q=26.05\times49+19.5-3.4=1292.5$.	
gg	Aliphatic radical : N : (Aliphatic radical)$_2$	+26.0
	(Tertiary aliphatic amines)	
hh	Aromatic radical carbon : — N (Ammonia type of nitrogen)	−3.5
jj	Aromatic radical :—N(H)—H	+6.5
	(Primary aromatic amine)	
	Example: *p*—Toluidine $Q=26.05\times37+6.5-3.5-3.5=963.3$.	
kk	Aromatic radical : N(H) : —aromatic radical	+13.0
	(Secondary aromatic amine)	
	Example: Diphenylamine $Q=26.05\times59+13.0-3.5\times2=1542.9$.	
ll	Aromatic radical : N : (Aromatic radical)$_2$	+19.5
	Example: Triphenylamine $Q=26.05\times87+19.5-3.5\times3=2275.3$.	
mm	For substituted amides, as in O=C(R) and N(H) : —N—CH_2—	+6.5

VI. STRUCTURAL CORRECTION FACTORS—Continued

Symbol	Pair of electrons held between—	For each such grouping add or subtract as indicated
nn	For Nitrile radical aliphatic or aromatic, RC≡N Example: Propionitrile $Q=26.05\times17+16.5=459.3$.	+16.5
pp	Aromatic radical carbon ⁘ C≡N Example: Benzonitrile $Q=26.05\times33+16.5-6.5=869.6$.	−6.5
qq	For Carbylamine radical, aliphatic R−N=C Example: Propyl carbylamine $Q=26.05\times23+33.1=632.2$.	+33.1
rr	Aliphatic radical ⁘ N(=O)=O Example: Nitromethane $Q=26.05\times6+13=169.3$.	+13.0
ss	Aromatic radical ⁘ N(=O)=O Examples: 1. Dinitrobenzene $Q=26.05\times26+13\times2=703.3$. 2. Nitrotoluene $Q=26.05\times34+13-3.5=895.2$.	+13

No equations are given for the fluorine, chlorine, and sulphur compounds. However, an examination of the data reveals that the general form of the equation $Q=26.05\times N+a$ holds fairly well, and it is only necessary to evaluate "a" to obtain the equations for these substances. In the case of sulphur compounds it is also necessary to use a factor different from 26.05 for the sulphur atoms which are burned to SO_2 or SO_3.

VII. INDEX OF COMPOUNDS, BY CLASSES

The compounds recorded in the tables are classified in accordance with the distinct types of organic molecules which they represent. The calculation of the heats of combustion is thus facilitated.[16]

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[16] A substance such as cinnamic acid would in this classification come under the heading of unsaturated aliphatic acid. Other similar substances were classified in the same manner.

2. CHO COMPOUNDS

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VIII. TABLES OF DATA

1. CH COMPOUNDS

1. SATURATED HYDROCARBONS (ALIPHATIC)

$Q = 26.05 \times N$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
CH_4	Methane (g)	16	8	[1] 210.8	881.6	208.4	223; cf. 136, 37, 2, 65.
C_2H_6	Ethane (g)	30	14	[2] 368.4	1,540.7	364.7	223; cf. 136.
C_3H_8	Propane (g)	44	20	[2] 526.3	2,201.0	521.0	223; cf. 136.
C_4H_{10}	Isobutane (g) (trimethylmethane).	58	26	[4] 683.4	2,858.0	677.3	223.
C_5H_{12}	*n*-Pentane (g)	72.10	32	838.3	3,511.6	833.6	170.
C_5H_{12}	*n*-Pentane	72.10	32	833.4	3,491.1	833.6	170.
C_5H_{12}	Isopentane (g)	72.10	32	843.5	3,533.4	833.6	170.
C_5H_{12}	Isopentane [5]	72.10	32	838.3	3,511.6	833.6	170.
C_5H_{12}	Tetramethylmethane (g)	72.10	32	[6] 842.6	3,523.8	833.6	223.
C_6H_{14}	*n*-Hexane	86.11	38	991.4 989.8	4,149.0 4,139.3	989.9	185. 215.
C_6H_{14}	Diisopropyl (v)	86.11	38	993.9	4,156.5	989.9	223.
C_7H_{16}	*n*-Heptane	100.13	44	1,137.3 1,149.9	4,756.2 4,812.3	1,146.2	114. 246.
C_7H_{16}	2-Methylhexane	100.13	44	1,148.9	4,808.1	1,146.2	246.
C_7H_{16}	3-Methylhexane	100.13	44	1,148.9	4,808.1	1,146.2	246.
C_7H_{16}	2,2-Dimethylpentane	100.13	44	1,148.9	4,808.1	1,146.2	246.
C_7H_{16}	2,3-Dimethylpentane	100.13	44	1,148.9	4,808.1	1,146.2	246.
C_7H_{16}	3,3-Dimethylpentane	100.13	44	1,147.9	4,804.0	1,146.2	246.
C_7H_{16}	2,4-Dimethylpentane	100.13	44	1,148.9	4,808.1	1,146.2	246.
C_7H_{16}	3-Ethylpentane	100.13	44	1,149.9	4,812.3	1,146.2	246.
C_7H_{16}	2,2,3-Trimethylbutane	100.13	44	1,147.9	4,804.0	1,146.2	246.
C_8H_{18}	*n*-Octane	114.14	50	1,302.7 1,304.7 1,305.2	5,447.9 5,458.9 5,467.5	1,302.5	215. 154. 163.
C_8H_{18}	2,5-Dimethylhexane	114.14	50	1,303.3	5,453.0	1,302.5	154.
C_8H_{18}	2-Methylheptane	114.14	50	1,306.1	5,464.7	1,302.5	154.
C_8H_{18}	3,4-Dimethylhexane	114.14	50	1,303.7	5,454.7	1,302.5	154.
C_8H_{18}	3-Ethylhexane	114.14	50	1,302.3	5,448.8	1,302.5	154.
C_8H_{18}	2,2,4-Trimethylpentane	114.14	50	1,303.9	5,457.0	1,302.5	246.
C_8H_{18}	Hexamethylethane (s)	114.14	50	1,301.8	5,448.3	1,302.5	246.
$C_{10}H_{22}$	Decane	142.18	62	1,610.2	6,733.9	1,615.1	215.
$C_{10}H_{22}$	Diisoamyl	142.18	62	1,615.8	6,757.3	1,615.1	153; cf. 244.
$C_{16}H_{34}$	Hexadecane (s)	226.27	98	2,559.1	10,709.8	2,552.9	192.
$C_{20}H_{42}$	Eicosane (s)	282.34	122	3,183.1	13,321.3	3,178.1	192.

[1] The above value is the average of 9 determinations which show a maximum variation of 1.1 per cent.
[2] The variation between the highest and lowest result equals 1.1 per cent.
[3] The variation between the highest and lowest result equals 0.9 per cent.
[4] The variation between the highest and lowest result equals 0.4 per cent.
[5] Note the large difference obtained by (170) for the two isomeric pentanes. This difference is rather unusual, particularly in view of the fact that the 9 isomeric heptanes recorded in this report show almost identical heats of combustion. The heptanes used for this purpose at the Bureau of Standards were of a very high degree of purity. In view of that fact, no great reliance should be attached to the value for isopentane until it is substantiated by other determinations.
[6] Value uncertain, since tetramethylmethane mixed with butylene was burned. The variation between the highest and lowest result equals 0.2 per cent.

VIII. TABLES OF DATA—Continued

1. CH COMPOUNDS—Continued

[2. POLYMETHYLENES

$Q = 26.05 \times N$ [7]

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
C_3H_6	Trimethylene (g)	42	18	496.8	2,077.6	----------	223; cf. 37.
C_5H_{10}	Methylcyclobutane	70.08	30	784.2	3,279.5	781.5	215.
C_5H_{10}	Cyclopentane	70.08	30	783.6	3,277.0	781.5	215.
C_6H_{12}	Methylcyclopentane	84.10	36	937.9	3,922.3	937.8	215.
C_6H_{12}	Cyclohexane	84.10	36	936.3 937.2 940.6	3,915.6 3,925.9 3,933.6	937.8 ---------- ----------	215. 165. 152.
C_6H_{10}	Bicyclohexane (0,1,3)	82.08	34	912.5	3,818.8	----------	91.
C_7H_{14}	1,3-Dimethylcyclopentane	98.11	42	1,090.7	4,561.3	1,094.1	215.
C_7H_{14}	Methylcyclohexane	98.11	42	1,091.8	4,565.9	1,094.1	215; cf. 114.
C_7H_{14}	Cycloheptane	98.11	42	1,087.3	4,547.1	1,094.1	114.
C_7H_{12}	Bicycloheptane	96.10	------	1,030.3	4,308.7	----------	163.
C_8H_{16}	1,2,4-Trimethylcyclopentane	112.13	48	1,245.4	5,208.3	1,250.4	215.
C_8H_{16}	1,1-Dimethylcyclohexane	112.13	48	1,242.5	5,196.1	1,250.4	215.
C_8H_{16}	1,3-Dimethylcyclohexane	112.13	48	[8] 1,238.0	5,177.3	1,250.4	215.
C_8H_{16}	1,4-Dimethylcyclohexane	112.13	48	[8] 1,228.8	5,138.8	1,250.4	215.
C_8H_{16}	Methylcycloheptane	112.13	48	1,244.5	5,204.5	1,250.4	215.
C_9H_{18}	Methyl-1-n-propylcyclopentane.	126.14	54	1,401.4	5,860.7	1,406.7	215.
C_9H_{18}	1,2,3-Trimethylcyclohexane	126.14	54	1,396.0	5,837.7	1,406.7	215.
C_9H_{18}	1,3,3-Trimethylcyclohexane	126.14	54	[8] 1,394.7	5,832.6	1,406.7	215.
C_9H_{18}	1,3,4-Trimethylhexahydrobenzene.	126.14	54	[9] 1,383.0	5,783.7	1,406.7	144.
C_9H_{18}	Ethylcycloheptane	126.14	54	1,406.8	5,883.2	1,406.7	215.
$C_{10}H_{18}$	Fenchane	138.14	58	1,502.8	6,284.7	1,510.9	215.
$C_{10}H_{18}$	Thujane	138.14	58	1,506.4	6,310.3	----------	175.
$C_{10}H_{18}$	Decahydronaphthalene (*cis*).	138.14	58	1,502.5	6,288.0	1,510.9	169; cf. 173, 82.
$C_{10}H_{18}$	Decahydronaphthalene (*trans*).	138.14	58	1,499.5 1,497.4	6,275.4 6,266.6	1,510.9 ----------	105. 173; cf. 82.
$C_{10}H_{20}$	Methyl-1-*n*-propyl-3-cyclohexane.	140.16	58	1,502.9	6,285.1	1,510.9	215.
$C_{10}H_{20}$	*p*-Menthane [10] (1-Isopropyl-4-methylcyclohexane).	140.16	60	1,514.6	6,334.1	1,563.0	215.
$C_{14}H_{26}$	3,3-Dimethyldicyclohexyl (*m*-Hexahydroditolyl).	194.21	82	2,105.9	8,806.9	2,136.1	215.

Except for trimethylene and its derivatives and bicyclo compounds containing trimethylene rings.

Swietoslawski (J. Am. Ch. Soc., 42, p. 1315), 1920, believes that the heats of combustion of these compounds are in error and recommends that they be redetermined.

[9] This value is probably in error. The work of this investigator does not agree well with the values of modern workers.

[10] The author (215) calls the compound "Caromenthane." The heat of combustion of this compound would certainly bear reinvestigation.

VIII. TABLES OF DATA—Continued

1. CH COMPOUNDS—Continued

3. AROMATIC HYDROCARBONS

$Q = 26.05 \times N - 3.5a - 6.5b$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
C_6H_6	Benzene (v)	78.05	30	787.2	3,294.4	----------	200.
C_6H_6	Benzene	78.05	30	783.4	3,277.7	781.5	153.
				782.3	3,277.1	----------	165; cf. 154.
C_7H_8	Toluene	92.06	36	937.0	3,920.4	934.3	152.
				934.2	3,913.4	----------	165; cf. 203, 153.
C_8H_{10}	*o*-Xylene	106.08	42	1,094.2	4,578.1	1,087.1	154.
				1,091.7	4,567.7	----------	152.
C_8H_{10}	*m*-Xylene	106.08	42	1,091.7	4,567.7	1,087.1	152.
				1,088.4	4,559.3	----------	165; cf. 154, 203.
C_8H_{10}	*p*-Xylene	106.08	42	1,089.1	4,556.8	1,087.1	154; cf. 152.
C_8H_{10}	Ethylbenzene	106.08	42	1,091.2	4,565.6	1,087.1	152; cf. 138. 4.[11]
C_9H_{12}	Mesitylene	120.10	48	1,243.6	5,203.2	1,239.9	152; cf. 203.
C_9H_{12}	*n*-Propylbenzene	120.10	48	1,246.4	5,214.9	1,246.9	152; cf. 73.
C_9H_{12}	Isopropylbenzene	120.10	48	1,247.3	5,218.7	1,246.9	152; cf. 73.
C_9H_{12}	Pseudocumene (1,2,4-Trimethylbenzene).	120.10	48	1,241.7	5,195.3	1,239.9	152.
$C_{10}H_{14}$	*tert*-Butylbenzene	134.11	54	1,400.4	5,859.3	1,403.2	152; cf. 153.
$C_{10}H_{14}$	1,2,4,5-Tetramethylbenzene (s) (Durene).	134.11	54	1,393.6	5,832.2	1,392.7	188.
$C_{10}H_{14}$	*iso*-Propyltoluene (1,4) (Cymene).	134.11	54	1,412.3	5,910.5	1,399.7	182.
				1,402.8	5,866.5	----------	203.
$C_{10}H_{14}$	*n*-Propyltoluene (1,3)	134.11	54	[12] 1,405.4	5,878.8	1,399.7	73.
$C_{10}H_{14}$	Isopropyltoluene (1,3)	134.11	54	[12] 1,409.5	5,895.9	1,399.7	73.
$C_{11}H_{16}$	Pentamethylbenzene (s)	148.13	60	1,554.0	6,503.5	1,545.5	188.
$C_{12}H_{18}$	Hexamethylbenzene (s)	162.14	66	1,711.9	7,164.3	1,700.3	188.
$C_{13}H_{12}$	Diphenylmethane (s)	168.10	64	1,655.0	6,926.2	1,660.2	182; cf. 179.
$C_{14}H_{14}$	Dibenzyl (s)	182.11	70	1,810.6	7,577.4	1,816.5	182.
$C_{19}H_{15}$	Triphenylmethyl (s) [13]	243.12	91	[14] 2,378.5	9,946.9	2,373.5	179.
$C_{19}H_{16}$	Triphenylmethane (s)	244.13	92	2,379.3	9,957.4	2,386.1	182.
				2,388.7	9,996.9	----------	179.
$C_{38}H_{30}$	Tetraphenylmethane (s)	320.16	120	3,102.4	12,974.2	3,112.0	179.

[11] The authors (4) report the heats of combustion of two samples of ethylbenzene prepared by the Fittig and Clemensen methods, respectively. The calorimetric determinations were carried out by Langbein and agree within 0.1 per cent with the value recorded by (152). Of interest is the fact that, while the two samples have almost identical heats of combustion within 0.2 per cent, the sample obtained by the Clemensen method has the higher density and index of refraction.

[12] The values of this investigator are about 0.4 per cent too high as compared with those of Richards and Barry (16).

[13] The author (179) gives, also, the heat of combustion of triphenylmethyl peroxide and the heat of combustion of the addition product of hexaphenylethane and ethyl acetate.

[14] This molecule contains one displaced electron; hence the formula for it becomes $26.05 \times N + 13 = 2{,}373.5$.

4. AROMATIC HYDROCARBONS

(Two or more aromatic nuclei linked together)

$Q = 26.05 \times N - 3.5a - 6.5b$

$C_{10}H_8$	Naphthalene (s)	128.06	48	1,232.5	5,158.0	1,223.4	80.
				1,231.8	5,150.2	----------	52.
				1,229.9	5,147.1	----------	221; cf. 188, 241, 232, 63.
$C_{12}H_{10}$	Diphenyl (s)	154.08	58	1,493.6	6,250.7	1,497.9	188; cf.47.[15]
$C_{12}H_{10}$	Acenaphthene (s), (*peri*-ethylenenaphthylene).	154.08	58	1,491.3	6,241.1	1,491.0	182.

[15] These authors give the heats of combustion of a freshly prepared sample of diphenyl and one 20 years old, the difference being 11.2 kg-cal$_{15}$ per mole. The authors accept the higher value of 1,510.1 kg-cal$_{15}$ for the fresh sample as the correct value and believe that the new sample is of a higher degree of purity than the old sample.

VIII. TABLES OF DATA—Continued

1. CH COMPOUNDS—Continued

4. AROMATIC HYDROCARBONS—Continued

(Two or more aromatic nuclei linked together)

$Q = 26.05 \times N - 3.5a - 6.5b$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_{13}H_{10}$	Fluorene (s)	166.08	62	1,584.9	6,628.1	1,595.1	163.
$C_{14}H_{10}$	Anthracene (s)	178.08	66	1,693.4 1,700.4 1,691.6	7,086.9 7,116.2 7,079.3	1,705.3	188. 240. 217.
$C_{14}H_{10}$	Phenanthrene (s)	178.08	66	1,692.5	7,083.1	1,693.3	188.
$C_{18}H_{12}$	Chrysene (s)	228.10	84	2,139.1	8,952.1	2,159.2	182.
$C_{18}H_{18}$	Retene (s) (Methylisopropylphenanthrene).	234.14	90	2,306.8	9,653.9	2,311.5	182.
$C_{24}H_{18}$	1,3,5-Triphenylbenzene (s)	306.14	114	2,936.7	12,290.1	2,940.2	182.
$C_{28}H_{20}$	Dianthracene (s)	356.16	------	3,382.9	14,147.3	----------	240.

5. UNSATURATED COMPOUNDS

(Aliphatic-ethylene)

$Q = 26.05 \times N + 13$

C_2H_4	Ethylene (g)	28	12	345.4 [16] 331.6	1,444.5 1,387.8	325.6	136. 223.
C_3H_6	Propylene (g)	42	18	490.2	2,051.5	481.9	223; cf. 37.
C_4H_8	Isobutylene (g)	56	24	647.2	2,708.5	638.2	223.
C_5H_{10}	Amylene	70	30	803.4	3,362.2	794.5	65; cf. 98.
C_6H_{10}	Trimethylethylene (v) Trimethylethylene liquid	70 70.08	30 ------	803.6 796.0	3,363.1 3,328.9	794.5 ----------	223. 215.
C_6H_{12}	Hexylene	84.10	36	952.6	3,983.8	950.8	215.
C_6H_{10}	Diallyl (v)	82	34	928.1 903.4	3,884.1 3,778.0	911.7 ----------	223. 38.
C_8H_{16}	Diisobutylene [17]	112.13	48	1,252.4	5,237.5	1,263.4	128.
$C_{10}H_{20}$	Diamylene	140.16	60	1,582.2	6,616.8	1,576.0	65.
$C_{12}H_{24}$	Triisobutylene [18]	168.19	72	1,858.3	7,771.4	1,888.6	128.

[16] Thomsen's value is probably more reliable than the higher value of Mixter.
[17] $(CH_3)_2$ CH.CH:CH.CH.$(CH_3)_2$.
[18] $(CH_3)_2$.CH.C[CH_2.CH.$(CH_3)_2$]: CH.CH $(CH_3)_2$.

6. UNSATURATED HYDROCARBONS

(Aromatic)

$Q = 26.05 \times N + 13 - 6.5d$

C_8H_8	Styrene (Phenylethylene)	104.06	40	1,045.4 1,047.1	4,375.0 4,386.3	1,048.5 ----------	182. 7; cf. 138, 104.[19,20]
C_9H_{10}	α-Methylstyrene	118.08	46	1,202.9	5,038.9	1,204.8	7; cf. 104.
C_9H_{10}	β-Methylstyrene (p-Tolylethylene).	118.08	46	1,202.4	5,036.9	1,204.8	163; cf. 7, 104.
$C_{10}H_{12}$	α, β-Dimethylstyrene (s)	132.10	52	1,357.2	5,685.3	1,361.1	7.
$C_{10}H_{12}$	β-Ethylstyrene	132.10	52	1,346.1	5,638.8	1,361.1	6; cf. 7.

[19] The author (104) gives values for styrene and substitution products of that compound which are about 1.4 per cent higher than the values given by (7). As the details of the former (8) work are entirely lacking, and since, in general, the work of (7) is most painstaking, we may safely assume that the values of (104) are in error, and that his results are at least 0.8 per cent too high. No greater accuracy than 0.3 to 0.5 per cent can even then be attached to his values.

[20] Recently Swietoslawski and Popov (J. chim. phys., 22, p. 397; 1925) have attempted to correct Lemoult's values by introducing a correction of −0.5 per cent. While it is possible that the result of this investigator contains a systematic error, yet we do not believe that this correction brings all of Lemoult's values into agreement with those of later investigators, which indicates other sources of error. In the tables the corrected values are recorded.

VIII. TABLES OF DATA—Continued

1. CH COMPOUNDS—Continued

6. UNSATURATED HYDROCARBONS—Continued

(Aromatic)

$Q = 26.05 \times N + 13 - 6.5d$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_{10}H_{12}$	Phenyl-1-butene-2	132.10	52	1,361.2	5,702.1	1,364.1	7.
$C_{10}H_{12}$	Phenyl-1-butene-3	132.10	52	1,356.9	5,675.9	1,364.1	138.
$C_{11}H_{14}$	Phenyl-1-pentene-2	146.11	58	1,510.0	6,325.4	1,517.4	6.
$C_{12}H_{16}$	β,β-Diethylstyrene	160.13	64	1,664.9	6,974.3	1,673.7	6; cf. 7.
$C_{14}H_{12}$	Stilbene (s) (symm. Diphenylethylene).	180.10	68	1,765.0	7,381.2	1,771.4	183; cf. 163, 144, 9.
$C_{14}H_{12}$	Isostilbene	180.10	68	1,770.9	7,405.9	1,771.4	9.
$C_{15}H_{14}$	α,β-Methylphenylstyrene (s).	194.11	74	[21] 1,937.9	8,106.2	1,927.7	104.
$C_{16}H_{14}$	Diphenylbutadiene (s) (labile).	206.11	78	2,056.9	8,608.1	2,044.9	172.
$C_{16}H_{14}$ [22]	Diphenylbutadiene (s) (*cis-cis*).	206.11	78	2,035.1	8,516.9	2,044.9	172.
$C_{16}H_{14}$	Diphenylbutadiene(s) (*trans-trans*).	206.11	78	2,030.3	8,496.8	2,031.9	172.[23]
$C_{16}H_{16}$	Diphenylhexatriene (s)[23]	232.13	88	2,287.7	9,574.0	2,318.4	172.
$C_{18}H_{18}$	1, 6-Diphenylhexadiene-1, 5 (s).	234.14	90	2,342.2	9,811.5	2,355.5	163.
$C_{18}H_{18}$	Dibenzylbutadiene (s)	234.14	90	2,341.0	9,797.1	2,357.5	172.
$C_{18}H_{20}$	Diphenyl-1, 4-ethyl-1-butene-3.	[24]236.15	92	2,372.6	9,939.3	2,399.6	7.
$C_{28}H_{16}$	Diphenylstyrene (s)	256.13	96	[25] 2,508.6	10,493.5	2,494.3	164.

[21] This value is about 0.6 per cent too high. A better value would be 1,929.2 See footnotes 19 and 20, p. 376.

[22] For *trans* isomers the correction is 6.5 for the double bond. Consult p. 368.

[23] The purity of this product is rather questionable.

[24] $C_6H_5.CH(CH_2.CH_3).CH_2.CH=CH.C_6H_5$.

[25] The values of this investigator for this series are uniformly too high by 0.5 per cent. A better value would be 2,496.1 kg-cal$_{15}$.

7. HYDROAROMATIC HYDROCARBONS [26]

(Unsaturated)

$Q = 26.05 \times N + 6.5e$

C_6H_8	Dihydrobenzene	80.06	32	833.2	3,484.4	846.6	215.
				847.8	3,548.0		197.
C_6H_{10}	Dimethylmethylenecyclopropane.	82.08	34	898.0	3,755.4		215.
C_6H_{10}	Tetrahydrobenzene (cyclohexene).	82.08	34	891.2	3,727.0	892.2	215.
				893.7	3,743.7		165.
				891.9	3,732.6		197; cf. 91.[27]
C_7H_{12}	Methyl-1-cyclohexene-3	96.10	40	1,043.6	4,364.3	1,048.5	215
C_7H_{12}	Methyl-1-cyclohexene-1	96.10	40	1,040.9	4,353.0	1,048.5	215.
				1,048.1	4,390.5		165; cf. 162.
C_7H_{12}	Methylenecyclohexane	96.10	40	1,044.1	4,366.4	1,055.0	215.
				1,051.4	4,404.2		162.
				1,054.9	4,414.8		91.
C_7H_{12}	Cycloheptene	96.10	40	1,049.9	4,390.7	1,048.5	215.
C_8H_{12}	1,Methyl-3-methylenecyclohexene-1.	108.10	44	1,149.2	4,814.0	1,165.7	162.
C_8H_{12}	1,3-Dimethyldihydrobenzene.	108.10	44	[28] 1,148.2	4,801.7	1,159.2	215.
C_8H_{12}	1,4-Dimethylcyclohexadiene-1,3.	108.10	44	1,152.2	4,826.6	1,159.2	165.
C_8H_{14}	Ethyl-1-cyclohexene-1	110.11	46	1,203.7	5,042.3	1,204.8	165; cf. 162.

[26] In the case of 1,4 conjugated systems, the correction factor for each double bond should be not 13, but a smaller value, say 6.5, in agreement with the lower reactivity of these compounds. It is, however, omitted here, for the data at hand do not allow one to draw far-reaching conclusions and are too conflicting.

[27] This author gives the heat of combustion of cyclohexene as 898.8 kg.-cal$_{15}$ Whether it is for constant volume or constant pressure he does not state, and he gives no experimental details of any kind except that he used the internationally accepted value for benzoic acid.

[28] Compare values obtained by (215) and (197) for dihydrobenzene.

VIII. TABLES OF DATA—Continued

1. CH COMPOUNDS—Continued

7. HYDROAROMATIC HYDROCARBONS—Continued

(Unsaturated)

$Q = 26.05 \times N + 6.5e$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
C_8H_{14}	Ethylenecyclohexane	110.11	46	1,207.7	5,059.1	1,211.3	163; cf. 162.
C_8H_{14}	Laurolene	110.11	46	1,192.7	4,987.9	1,204.8	215.
C_8H_{14}	*iso*-Laurolene (1,1,2-Trimethylcyclopentene-2).	110.11	46	1,193.3	4,990.4	1,204.8	215.
C_8H_{14}	1,3-Dimethylcyclohexene-3	110.11	46	1,194.5	4,995.4	1,204.8	215.
C_9H_{14}	1-Methyl-4-ethylcyclohexadiene-1,3.	122.11	50	1,310.8	5,490.9	1,315.5	165.
C_9H_{18}	Isopropyl-1-cyclohexene-1	124.13	52	1,340.8	5,611.2	1,361.1	168.
$C_{10}H_{10}$	Δ_1-Dihydronaphthalene	130.08	50	1,296.3 1,312.5	5,429.2 5,488.9	1,302.0	165. 105.
$C_{10}H_{10}$	Δ_2-Dihydronaphthalene(s)	130.08	50	1,298.3	5,438.6	1,302.0	165.
$C_{10}H_{12}$	Tetrahydronaphthalene	132.10	52	1,339.6 1,352.4	5,611.6 5,655.7	1,347.6	165. 105.
$C_{10}H_{14}$	Hexahydronaphthalene	134.11	54	1,419.3	5,935.5	1,419.7	105.
$C_{10}H_{16}$	Octohydronaphthalene	136.13	56	1,461.7	6,114.3	1,465.3	105.
$C_{10}H_{16}$	Isobutenyl-1-cyclohexene-1	136.13	56	1,461.8	6,123.5	1,478.3	167.
$C_{10}H_{16}$	1,5-dimethyl-3-vinylcyclohexene-1.	136.13	56	1,455.7	6,097.9	1,478.3	176; cf. 162.
$C_{10}H_{16}$	1-Methyl-4-isopropylcyclohexadiene-1,3.	136.13	56	1,470.7	6,160.8	1,471.8	165.
$C_{10}H_{18}$	1-Ethyl-5-dimethylcyclohexene-1.	138.14	58	1,504.5	6,302.4	1,517.4	171.
$C_{10}H_{18}$	Menthene (Δ_1-Terpene)	138.14	58	1,523.2	6,374.6	1,517.4	183.
$C_{11}H_{18}$	1,5-Dimethyl-3-isopropenylcyclohexene-1.	150.14	62	1,615.0	6,765.2	1,634.0	176.

8. TERPENES

$Q = 26.05 \times N + 13c + 6.5e$

$C_{10}H_{16}$	*l*-Limonene	136.13	56	1,457.2	6,094.0	1,477.5	215.
$C_{10}H_{16}$	*d*-Limonene	136.13	56	1,471.2	6,162.9	1,477.5	7.
$C_{10}H_{16}$	*d*-"Citrene"	136.13	56	1,473.0	6,164.5		32.
$C_{10}H_{16}$	*d*-α-Pinene (Australene)	136.13	56	1,471.9	6,155.5	1,465.3	215; cf. 7,8.
$C_{10}H_{16}$	*l*-α-Pinene (Terebenthene)	136.13	56	1,473.2 1,480.5	6,160.9 6,195.9	1,465.3	215. 183; cf. 32.
$C_{10}H_{16}$	β-Pinolene	136.13	56	1,469.3	6,154.9		175.
$C_{10}H_{16}$	Sylvestrene	136.13	56	1,464.7	6,135.6	1,477.5	6.
$C_{10}H_{16}$	Camphene(s) cryst	136.13	56	1,467.6 1,468.8	6,147.8 6,144.0	1,471.8	6. 47.
$C_{10}H_{16}$	Terecamphene (*inact.*)	136.13	56	1,466.7	6,138.1	1,471.8	183.
$C_{10}H_{16}$	Borneocamphene	136.13	56	1,470.2	6,152.8	1,471.8	183.
$C_{10}H_{16}$	Cyclene(s) (Tricyclene)	136.13	56	1,467.3	6,146.5		175.
$C_{10}H_{16}$	α-Terpinene	136.13	56	1,470.4	6,159.5	1,471.8	163.

9. ACETYLENE HYDROCARBONS

$Q = 26.05 \times N + 33.1h + 46.1g$

C_2H_2	Acetylene (g) (Ethine)	26.02	10	[20] 312.0	1,304.8	306.1	137; cf. 223, 10.
C_3H_4	Allylene (g) (Propine)	40	16	465.1 473.0	1,945.5 1,978.6	462.9	223. 37; cf. 103.
C_6H_6	Dipropargyl (v) (1,5-Hexadiine).	78	30	853.5 882.9	3,570.2 3,694.9	873.7	12. 223.
C_6H_6	Dimethyldiacetylene (2,4-Hexadiine).	78.05	30	847.8	3,546.4	847.7	122.
C_7H_{12}	Heptine-1	96.10	40	1,091.2	4,564.5	1,088.0	138.
C_8H_6	Phenylacetylene (Phenylethine).	102.05	38	1,024.2	4,284.2	1,029.5	138.
$C_{10}H_{10}$	Phenyl-1-butine-3	130.08	50	1,340.0	5,605.2	1,342.1	138.
$C_{16}H_{10}$	Diphenyldiacetylene (s)	202.08	74	1,975.6	8,267.9	1,980.9	172.

[20] The author (137) gives also the heat of explosion of acetylene.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS

10. PRIMARY ALCOHOLS

$Q = 26.05 \times N + 13$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
CH_4O	Methyl alcohol	32.03	6	170.9	714.7	169.3	153; cf. 172, 191, 223.
C_2H_6O	Ethyl alcohol	46.05	12	327.6	1,370.0	325.6	153.
				329.4	1,378.5		172; cf. 3, 64.
C_3H_4O	Propargyl alcohol (v)	56.00	14	428.9	1,793.7	423.8	223.
C_3H_6O	Allyl alcohol	58.05	16	442.4	1,850.6	442.8	111.
C_3H_8O	*n*-Propyl alcohol	60.06	18	483.5	2,022.0	481.7	153.
				480.5	2,009.4		215; cf. 110.
$C_4H_{10}O$	*n*-Butyl alcohol	74.08	24	638.6	2,674.4	638.2	215.
				640.1	2,678.8		229; cf. 153.
$C_4H_{10}O$	Isobutyl alcohol (primary)	74.08	24	638.2	2,668.9	638.2	153; cf. 215.
$C_5H_{12}O$	Amyl alcohol (?)	88	30	787.3	3,293.3		65.
$C_5H_{12}O$	Amyl alcohol (ferm.)[30]	88.10	30	791.6	3,310.5	794.5	215.
				793.7	3,320.1		110.
$C_7H_{16}O$	*n*-Heptyl alcohol	116.13	42	1,104.9	4,620.7	1,107.1	215.
C_7H_8O	Benzyl alcohol	108.06	34	891.2	3,727.9	895.2	179.
				894.3	3,742.7		182; cf. 205.
$C_8H_{18}O$	Octyl alcohol	130.14	48	1,262.0	5,278.9	1,263.4	115.
$C_8H_{14}O$	Amylpropargyl alcohol [31]	126.11	44	1,191.9	4,984.5	1,192.3	138.
C_9H_8O	Phenylpropargyl alcohol [32]	132.06	42	1,137.3	4,757.33	1,133.7	138.
$C_9H_{16}O$	Hexylpropargyl alcohol	140.13	50	1,340.1	5,605.6	1,348.6	138.
$C_{16}H_{34}O$	Cetyl alcohol (s)	242.27	96	2,504.5	10,481.3	2,513.8	181.

[30] Mostly isobutyl carbinol. [31] $C_5H_{11}.C{\equiv}C{-}CH_2OH$. [32] $C_6H_5.C{\equiv}C{-}CH_2OH$.

11. PRIMARY ALCOHOLS (Cylic) [33]

$Q = 26.05 \times N + 13$

$C_6H_{10}O$	Cyclobutyl carbinol	86.08	28	747.8	3,127.3	742.4	215.
$C_7H_{14}O$	Cyclohexyl carbinol	114.11	40	1,047.2	4,379.4	1,055.0	215.

[33] Among the cyclic alcohols should be included cholesterol. However, it is omitted here because Berthelot and André, Ann. chim. phys., (7), **17**, p. 433; 1899, who determined the heat of combustion of cholesterol, give for the formula of the compound $C_{26}H_{44}O$. The present accepted formula is $C_{27}H_{46}O$.

12. SECONDARY ALCOHOLS

$Q = 26.05 \times N + 6.5$

C_3H_8O	Isopropyl alcohol	60.06	18	474.8	1,985.6	475.4	215; cf. 110.
$C_5H_{10}O$	Ethylvinyl carbinol	86.08	28	752.9	3,148.6	748.9	111.
$C_6H_{14}O$	Pinacolyl alcohol	102.11	36	938.6	3,925.2	944.3	215.
$C_7H_{12}O$	Diallyl carbinol	112.10	38	1,028.2	4,299.9	1,022.4	215.
$C_{13}H_{12}O$	Diphenyl carbinol (s)	184.10	62	1,615.4	6,760.5	1,614.6	182; cf. 179.
$C_{14}H_{18}O$	Amylphenylpropargyl alcohol.[34]	202.14	72	1,901.1	7,910.4	1,921.7	138.
$C_5H_{10}O_2$	Dimethylolcyclopropane	102.08		707.6	2,959.2		215.
$C_6H_{12}O$	β—Methylcyclopentanol	100.10	34	887.6	3,711.9	892.7	215.
$C_6H_{12}O$	Cyclohexanol	100.10	34	890.7	3,724.9	892.7	153; cf. 215.
$C_7H_{14}O$	1,3-Dimethylcyclopentanol-2	114.11	40	1,030.5	4,309.6	1,048.5	215.
$C_7H_{14}O$	Ethyl-1-cyclopentanol-2	114.11	40	1,039.0	4,345.1	1,048.5	215.
$C_7H_{14}O$	β-Methylcyclohexanol	114.11	40	1,038.4	4,342.6	1,048.5	215.
$C_7H_{14}O$	Cycloheptanol	114.11	40	1,050.2	4,391.9	1,048.5	215.
$C_8H_{18}O$	1-3-Dimethylcyclohexanol-2	128.13	46	1,196.0	5,001.7	1,204.8	215.
$C_8H_{16}O$	1,3-Dimethylcyclohexanol-5	128.13	46	1,183.4	4,949.0	1,204.8	215.
$C_9H_{18}O$	Cycloheptylmethyl carbinol	142.14	52	1,342.2	5,613.1	1,361.1	215.
$C_{10}H_{18}O$	Thujyl alcohol	154.14	56	1,477.5	6,189.3		175.
$C_{10}H_{18}O$	Borneol (Borneo camphor)	154.14	56	[35] 1,469.6	6,145.9	1,465.3	125.
$C_{10}H_{18}O$	Borneol (synthetic)	154.14	56	1,466.2	6,136.1	1,465.3	183; cf. 125
$C_{10}H_{18}O$	*d*-Borneol (s)	154.14	56	1,466.6	6,131.9	1,465.3	89.
$C_{10}H_{18}O$	*l*-Borneol	154.14	56	1,467.2	6,134.4	1,465.3	89.
$C_{10}H_{20}O$	Menthol (s)	156.16	58	1,508.8	6,309.8	1,517.4	113.

[34] $C_6H_{11}C{\equiv}C{-}CH(OH)(C_6H_5)$. [35] Mean value.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

13. HYDROAROMATIC AND POLYMETHYLENE SECONDARY ALCOHOLS

$Q = 26.05 \times N + 6.5$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_6H_{12}O_5$	Quercitol (s)	164.10	26	704.2	2,947.1	----------	195.
$C_6H_{12}O_6$	Inositol (s) (Inosite)	180.10	24	662.1	2,770.9	----------	195.

14. TERTIARY ALCOHOLS

$Q = 26.05 \times N + 3.5$

$C_4H_{10}O$	Trimethyl carbinol (*Tert.* butyl alcohol).	74.08	24	629.3	2,631.7	628.7	215; cf. 116.
$C_5H_{12}O$	Dimethylethyl carbinol	88.10	30	784.6	3,281.2	785.0	215; cf. 110.
$C_6H_{12}O$	Allyldimethyl carbinol	100.10	34	886.5 913.7	3,707.3 3,821.1	902.2 ----------	215. 113.
$C_6H_{14}O$	Methyldiethyl carbinol	102.11	36	927.0	3,876.7	941.3	215.
$C_7H_{14}O$	Allylmethylethyl carbinol	114.11	40	1,050.1	4,391.5	1,058.5	215.
$C_7H_{16}O$	Triethyl carbinol	116.13	42	1,080.0	4,516.6	1,097.6	215.
$C_8H_{14}O$	Diallylmethyl carbinol	126.11	44	1,180.7	4,937.7	1,175.7	215; cf. 113.
$C_8H_{16}O$	Allylmethylpropyl carbinol	128.13	46	1,201.9	5,026.4	1,214.8	215.
$C_8H_{16}O$	Allyldiethyl carbinol	128.13	46	1,207.1	5,048.1	1,214.8	215.
$C_8H_{18}O$	Methyldipropyl carbinol	130.14	48	1,232.7	5,155.2	1,253.9	215.
$C_8H_{18}O$	Allylmethyl-*n*-butyl carbinol.	142.14	52	1,364.9	5,708.0	1,371.1	215.
$C_9H_{18}O$	Allylmethyl-*tert.*-butyl carbinol.	142.14	52	1,363.0	5,700.0	1,371.1	215.
$C_9H_{20}O$	Ethyldipropyl carbinol	144.16	54	1,386.5	5,798.3	1,410.2	215.
$C_{10}H_{18}O$	Diallylpropyl carbinol	154.14	56	1,472.1	6,156.3	1,488.3	215.
$C_{10}H_{20}O$	Allyldipropyl carbinol	156.16	58	1,518.0 1,549.6	6,348.3 6,480.4	1,527.4 ----------	215. 113.
$C_{11}H_{22}O$	Allylmethylhexyl carbinol	170.18	64	1,666.7	6,970.1	1,683.7	215.
$C_{19}H_{16}O$	Triphenyl carbinol (s)	260.13	90	2,340.8	9,796.3	2,337.5	182; cf. 179.
$C_{21}H_{16}O$	Diphenylphenylethinyl carbinol.[36]	284.12	98	2,572.3	10,757.4	2,576.0	95.
$C_7H_{14}O$	1,3-Dimethylcyclopentanol-3	114.11	40	1,034.0	4,324.2	1,045.7	215.
$C_8H_{16}O$	1,2-Dimethylcyclohexanol-2	128.13	46	1,196.5	5,012.1	1,201.8	163.
$C_8H_{16}O$	1,3-Dimethylcyclohexanol-3	128.13	46	1,192.5	4,987.0	1,201.8	215.
$C_9H_{16}O$	1,3,5-Trimethylcyclohexene-6-ol-5.	140.13	50	1,294.7	5,414.4	1,312.5	215.
$C_9H_{18}O$	1-Methyl-3-ethylcyclohexanol-3.	142.14	52	1,322.4	5,530.3	1,358.1	215.
$C_{10}H_{18}O$	Terpineol (s)	154.14	56	1,469.5 up to 1,480.0	6,145.4 up to 6,189.4	1,468.8	125.
$C_{10}H_{22}O_3$	Terpine hydrate (s)	190.18	56	1,451.0	6,068.1	----------	125.

[36] $(C_6H_5)_2:-C(OH)-C\equiv C-C_6H_5$.

15. POLYHYDROXY ALIPHATIC ALCOHOLS

$Q = 26.05 \times N + 13j + 6.5k + 3.5l$

$C_2H_6O_2$	Ethylene glycol [37]	62.05	10	281.9	1,179.8	286.5	195; cf. 109.
$C_3H_8O_2$	Propylene glycol	76.06	16	431.0	1,802.4	436.3	111.
$C_3H_8O_2$	Isopropylene glycol	76.06	16	436.1	1,823.8	442.8	111.
$C_3H_8O_3$	Glycerol	92.06	14	397.0	1,661.5	397.2	195; cf. 181, 64.
$C_4H_{10}O_4$	Erythritol (s)	122.08	18	504.1	2,109.7	507.9	182; cf. 126, 31.
$C_5H_{12}O_4$	Pentaerythritol (s)	136.10	24	661.2	2,767.1	657.7	195.
$C_5H_{12}O_5$	Arabitol (s)	152.10	22	611.8	2,560.4	618.6	195.
$C_6H_{14}O_2$	Pinacol (s) (Tetramethylethylene glycol).	118.11	34	897.6	3,753.8	898.7	115.

[37] The heat of combustion of diethylene glycol, $HO-CH_2.CH_2.O-CH_2.CH_2OH$ (liq.), is given by Wm. H. Rinkenbach (156) as 566.7 kg.-cal$_{15}$ per mole. No experimental details as to procedure employed are given.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

15. POLYHYDROXY ALIPHATIC ALCOHOLS—Continued

$Q = 26.05 \times N + 13j + 6.5k + 3.51$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_6H_{14}O_6$	*d*-Mannitol (s)	182.11	26	727.6	3,045.0	729.4	195; cf. 182.
$C_6H_{14}O_6$	Dulcitol (s)	182.11	26	729.1 723.7	3,049.1 3,028.7	729.4	48. 195.
$C_7H_{16}O_7$	Perseitol (Glucoheptol) (s) (*d*-mannoheptol).	212.13	30	835.8	3,497.8	840.0	195; cf. 68.
$C_8H_{14}O_2$	Tetramethylbutinediol	142.11	42	1,142.3	4,780.5	1,134.2	173.
$C_8H_{16}O_2$	Tetramethylbutenediol (s) (Maleinoid).	144.13	44	1,172.3	4,906.1	1,166.2	173.
$C_8H_{16}O_2$	Tetramethylbutenediol (s) (Fumaroid).	144.13	44	1,175.7	4,920.3	1,166.2	173.
$C_{14}H_{14}O_2$	Hydrobenzoin (s) [38]	214.11	66	1,723.0	7,210.8	1,725.3	10.
$C_{14}H_{14}O_2$	Isohydrobenzoin (s) [38]	214.11	66	1,727.8	7,230.8	1,725.3	10.

[38] The form used is not indicated. See, however, Erlenmeyer, jr., Ber., **30**, p. 1537; 1897.

16. HYDROAROMATIC AND POLYMETHYLENE GLYCOLS

(All types)

$Q = 26.05 \times N + 13j + 6.5k + 3.51$

$C_5H_{10}O_2$	Cyclopentanediol-1,2 (*cis*). [39]	102.08	26	696.1	2,913.2	690.3	237.
$C_5H_{10}O_2$	Cyclopentanediol-1,2 (*trans*).	102.08	26	694.2	2,905.2	690.3	237.
$C_6H_{12}O_2$	Cyclohexanediol-1,2 (*cis*)	116.09	32	841.6	3,522.1	846.3	237.
$C_6H_{12}O_2$	Cyclohexanediol-1,2 (*trans*)	116.09	32	842.7	3,526.7	846.3	237.
$C_7H_{14}O_2$	1-Methylcyclohexane-1,2-diol (*cis*).	130.11	38	992.6	4,154.0	999.9	237.
$C_7H_{14}O_2$	1-Methylcyclohexane-1,2-diol (*trans*).	130.11	38	995.1	4,164.5	999.9	237.
$C_9H_{10}O_2$	Hydrindene-1,2-diol (*cis*)	150.08	42	1,098.5	4,597.2	1,100.1	237.
$C_9H_{10}O_2$	Hydrindene-1,2-diol (*trans*)	150.08	42	1,096.7	4,589.7	1,100.1	237.
$C_{10}H_{12}O_2$	1,2,3,4-Tetrahydronaphthalene-1,2-diol (*cis*).	164.09	48	1,250.7	5,234.2	1,256.4	237.
$C_{10}H_{12}O_2$	1,2,3,4-Tetrahydronaphthalene-1,2-diol (*trans*).	164.09	48	1,249.4	5,228.7	1,256.4	237.
$C_{10}H_{12}O_2$	1,2,3,4-Tetrahydronaphthalene-2,3-diol (*cis*).	164.09	48	1,250.9	5,235.0	1,256.4	237.
$C_{10}H_{12}O_2$	1,2,3,4-Tetrahydronaphthalene-2,3-diol (*trans*).	164.09	48	1,249.4	5,228.7	1,256.4	237.
$C_{12}H_{16}O_2$	1-Phenylcyclohexane-1,2-diol (*cis*).	192.12	60	1,563.1	6,541.6	1,569.5	237.
$C_{12}H_{16}O_2$	1-Phenylcyclohexane-1,2-diol (*trans*).	192.12	60	1,564.9	6,549.1	1,569.5	237.

[39] The heats of combustion of the acetates and benzoates of these compounds are given below (observer 237):

	Cis.		*Trans.*	
	Kg-cal$_{15}$	Kilojoules	Kg-cal$_{15}$	Kilojoules
1. Cyclopentane-1,2 diacetate (liq.)	1,114.7	4,665.0	1,114.1	4,662.5
2. Cyclopentane-1,2 dibenzoate (s)	2,242.5	9,384.9	2,240.3	9,375.7
3. Cyclohexane-1,2 diacetate (liq.)	1,261.6	5,279.8	1,263.4	5,287.3
4. Cyclohexane-1,2 dibenzoate (s)	2,392.6	10,013.0	2,388.7	9,996.7
5. 1-Methylcyclohexane-1,2 dibenzoate			2,545.1	10,651.2
6. Hydrindene-1,2 diacetate	1,515.8 (s)	6,343.6	1,519.3 (liq.)	6,358.3
7. Hydrindene-1,2 dibenzoate	2,645.3	11,070.6	2,647.1	11,078.1
8. Tetrahydronaphthalene-1,2 diacetate (s)			1,667.0	6,976.4
9. Tetrahydronaphthalene-1,2 dibenzoate			2,798.1	11,710.1
10. Tetrahydronaphthalene-2,3 dibenzoate	2,797.8	11,708.8	2,799.6	11,716.3

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

17. PHENOLS

$Q = 26.05 \times N + 3.5 - 3.5a - 6.5b$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
C_6H_6O	Phenol (s)	94.05	28	732.2	3,064.3	732.9	195; cf. 30.
$C_6H_6O_2$	Pyrocatechol (s)	110.05	26	684.8	2,865.9	684.3	195.
$C_6H_6O_2$	Resorcinol (s)	110.05	26	683.0	2,858.4	684.3	195.
$C_6H_6O_2$	Hydroquinol (s)	110.05	26	682.9 683.7	2,857.9 2,859.2	684.3	195. 225; cf. 30, 180.
$C_6H_6O_3$	Pyrogallol (s)	126.05	24	638.7	2,672.9	635.7	195; cf. 30.
$C_6H_6O_3$	Phloroglucinol (s)	126.05	24	[40] 617.3	2,583.4	635.7	202.
C_7H_8O	*o*-Cresol	108.06	34	[41] 882.6	3,693.7	885.7	201.
	o-Cresol (s)	108.06	34	879.5	3,680.7		201.
C_7H_8O	*m*-Cresol	108.06	34	880.5 895.1	3,684.9 [42] 3,746.0	885.7	201. 211.
C_7H_8O	*p*-Cresol [43]	108.06	34	882.5	3,693.3	885.7	211.
	p-Cresol (s)	108.06	34	880.0	3,682.8		211.
$C_7H_8O_2$	Orcinol (s)	124.06	32	824.3	3,449.7	837.1	201.
$C_7H_8O_2$	Saligenin (s)	124.06	32	845.4	3,535.5	846.6	44.
$C_7H_8O_2$	Toluhydroquinol (s)	124.06	32	835.1	3,494.9	837.1	225.
$C_8H_{10}O$	*o*-Xylenol (s)	122.08	40	1,035.1	4,331.9	1,038.5	201.
$C_8H_{10}O$	*m*-Xylenol (s)	122.08	40	1,037.4	4,341.5	1,038.5	201.
$C_8H_{10}O$	*p*-Xylenol (s)	122.08	40	1,035.3	4,332.7	1,038.5	201.
$C_9H_{12}O$	Pseudocumenol (s)	136.10	46	1,191.2	4,985.2	1,191.3	201.
$C_{10}H_8O$	α-Naphthol (s)	144.06	46	1,185.4	4,960.9	1,188.8	225.
$C_{10}H_8O$	β-Naphthol (s)	144.06	46	1,187.2	4,968.4	1,188.8	225.
$C_{10}H_{14}O$	Thymol	150.11	52	1,353.4	5,663.9	1,351.1	201.
	Thymol (s)			1,349.7	5,648.5		201.
$C_{10}H_{14}O$	Carvacrol	150.11	52	1,354.5	5,668.6	1,351.1	201.
$C_{10}H_{14}O_2$	Thymohydroquinol (s)	166.11	50	1,307.1	5,470.2	1,302.5	225.
$C_{14}H_{10}O_2$	Phenanthrahydroquinol (s).	210.08	62	1,600.1	6,696.4	1,602.6	225.
$C_{21}H_{16}O_2$	β-Dioxydinaphthylmethane (s).	300.13	96	2,475.8	10,353.8	2,474.8	60.

[40] The determinations by (202) were carried out in oxygen at ordinary pressure and differ greatly from later determinations by (195). Thus, (202) give for pyrogallol 616.3 kg-cal$_{15}$, but (195) give 639.0 kg-cal$_{15}$ per mole. The above value for phloroglucinol is undoubtedly very low. It should be approximately the same as that for pyrogallol.

[41] It is quite possible that the same objection and the inherent error in the determinations occur also in the values of (201) as occur in (202). See footnote 40.

[42] This value is undoubtedly too high.

[43] M. F. Barker, J. Phys. Chem. **29**, p. 1350, 1925, reports the following values for the three cresols at constant pressure: *o*-(s), 883.7; *p*-(s), 885.0; *m*-(liq.), 883.0. However, no experimental details are available except the final values.

18. ALIPHATIC ETHERS [44]

$Q = 26.05 \times N + 19.5$

C_2H_6O	Dimethyl ether (g)	46	12	347.6	1,453.7		223; cf. 10.
C_3H_8O	Methylethyl ether (v)	60	18	503.4	2,105.2		223.
C_4H_6O	Methylpropargyl ether (v)	70.00	20	600.8	2,512.6		223.
C_4H_8O	Methylallyl ether (v)	72.00	22	623.9	2,609.2		223.
$C_4H_{10}O$	Diethyl ether	74.08	24	651.7	2,727.4		204.
	Diethyl ether (v)			660.3	2,763.4		204.
$C_6H_{10}O$	Diallyl ether (v)	98	32	906.6	3,791.4		223.
$C_6H_{10}O_2$	Acetylacetone-*O*-methyl ether.	114.08	30	817.8	3,422.5	820.5	166.
$C_6H_{14}O_2$	Glycoldiethyl ether	118.11	34	924.6	3,869.5	924.7	172.
$C_7H_{12}O_2$	Acetylacetone-*O*-ethyl ether	128.10	36	968.0	4,051.1	976.8	166.
$C_{10}H_{22}O$	Diamyl ether	158.17	60	1,609.3	6,730.1	1,582.0	65.

[44] For heat of combustion of diethylene glycol, see footnote (37), p. 380.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

19. ALIPHATIC ACETALS [45]

$Q = 26.05 \times N + 19.5 \times 0$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_3H_6O_2$	Glycolmethylal (Methyleneethylene dioxide).	74.05	14	409.9	1,715.43	403.7	59.
$C_3H_8O_2$	Methylal	76.06	16	462.8	1,936.8	455.8	26.
$C_4H_8O_2$	Glycolacetal (Ethylideneacetal of glycol).	88.06	20	559.2	2,340.3	560.1	59.
$C_4H_{10}O_2$	Dimethylacetal	90.09	22	620.0	2,594.7	612.1	58.
$C_4H_{10}O_3$	Methyl orthoformate (v)	106.0	20	[46] 596.8	2,495.8	579.5	223.
$C_5H_{12}O_2$	Diethylmethylal	104.10	28	774.5 [47] 773.8	3,241.3 3,238.4	768.2	58. 103.
$C_6H_{14}O_2$	Diethylacetal	118.11	34	923.0 931.2 919.5	3,862.8 3,897.1 3,848.1	924.7	157. 58. 117.
$C_6H_{10}O_4$	Erythritemethylal (s)	146.08	26	745.0	3,117.8		59.
$C_7H_{16}O_2$	Dipropylmethylal	132.13	40	1,085.9	4,544.5	1,081.1	58.
$C_7H_{14}O_6$	α-Methylglycoside (s)	194.11	30	842.5	3,529.2		241.
$C_8H_{14}O_4$	Erythritediacetal (s)	174.11	38	1,049.5	4,392.2	1,067.9	59.
$C_9H_{20}O_2$	Diisobutylmethylal	160.16	52	1,395.3	5,839.3	1,393.6	58.
$C_9H_{14}O_6$	Mannitetrimethylal (s)	218.11	38	1,084.1	4,536.9	1,074.4	59.
$C_{11}H_{24}O_2$	Diisoamylmethylal	188.19	64	1,708.7	7,150.9	1,706.2	58.
$C_{12}H_{20}O_6$	Mannitetriacetal (s)	260.16	56	1,539.0	6,440.7		59.
$C_{12}H_{22}O_2$	Amylpropiolic acetal	198.18	66	1,790.7	7,494.1	1,791.4	138.
$C_{12}H_{22}O_4$	Diacetal of acetylenedialdehyde (s).[48]	230.17	62	1,724.9	7,218.7	1,726.4	138.
$C_{13}H_{24}O_2$	Hexylpropiolic acetal	212.19	72	1,946.4	8,145.7	1,947.7	138.

[45] The values for acetals given by (58 and 59) are about 0.5 per cent to 1.0 per cent too high.
[46] Individual determinations do not agree better than 0.5 per cent.
[47] The values of (103) are about 0.6 per cent too high. Better value, 769.2 kg-cal$_{15}$.
[48] $(C_2H_5O)_2 : \overset{H}{C} - C \equiv C - \overset{H}{C} : (OC_2H_5)_2$.

20. AROMATIC ETHERS

$Q = 26.05 \times N + 19.5$

C_7H_8O	Anisole	108.06	34	905.1 900.9	3,787.8 3,770.3	905.2	196. 203.
$C_8H_{10}O$	Phenetole	122.08	40	1,056.9 1,060.3	4,423.1 4,437.4	1,061.5	203. 211.
$C_8H_{10}O$	*m*-Cresolmethyl ether	122.08	40	1,057.0	4,423.6	1,058.5	203.
$C_8H_{10}O_2$	Hydroquinoldimethyl ether (s).	138.08	38	1,014.7	4,246.5	1,028.9	203.
$C_8H_{10}O_2$	Resorcinoldimethyl ether	138.08	38	1,022.6	4,279.6	1,028.9	203.
$C_9H_{12}O$	Phenylpropyl ether	136.10	46	1,213.1	5,076.8	1,217.8	203.
$C_9H_{12}O$	*p*-Cresolethyl ether	136.10	46	1,212.8	5,075.6	1,214.3	203.
$C_9H_{12}O$	*m*-Xylenolmethyl ether	136.10	46	1,213.4	5,078.1	1,210.8	203.
$C_{10}H_{10}O_2$	Safrole	162.08	46	1,244.1	5,206.6	1,246.8	196.
$C_{10}H_{10}O_2$	Isosafrole	162.08	46	1,233.9	5,163.9	1,243.8	196.
$C_{10}H_{12}O$	Methylchavicole (*p*-Allylanisole).	148.10	50	1,334.6	5,585.3	1,331.5	196.
$C_{10}H_{12}O$	Anethole (s)	148.10	50	1,324.4	5,542.6	1,331.5	196.
$C_{10}H_{12}O$	α-Ethoxystyrene	148.10	50	1,314.7	5,507.3	1,328.5	163.
$C_{10}H_{12}O_2$	Eugenol	164.10	48	1,286.6	5,384.4	1,282.9	196.
$C_{10}H_{12}O_2$	Isoeugenol	164.10	48	1,277.6	5,346.8	1,279.9	196.
$C_{10}H_{12}O_2$	Allyl-3,4-guaiacol (Betelphenol).	164.10	48	1,286.4	5,383.6	1,282.9	196.
$C_{10}H_{14}O$	*p*-Xylenolethyl ether	150.11	52	1,368.6	5,727.6	1,366.1	203.
$C_{11}H_{14}O_2$	Methyleugenol	178.11	54	1,458.6	6,104.2	1,455.2	196.
$C_{11}H_{14}O_2$	Methylisoeugenol	178.11	54	1,447.4	6,057.4	1,452.2	196.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

20. AROMATIC ETHERS—Continued

$Q = 20.05 \times N + 19.5$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_{11}H_{16}O$	Thymolmethyl ether	164.13	58	1,524.3	6,379.2	1,523.4	203.
$C_{12}H_{14}O_4$	Apiole (s)	222.11	54	1,498.8	6,272.5	1,494.2	196.
$C_{12}H_{14}O_4$	Isoapiole (s)	222.11	54	1,488.2	6,228.1	1,491.2	196.
$C_{12}H_{16}O_2$	Ethylisoeugenol (s)	192.13	60	1,602.3	6,705.6	1,608.5	196.
$C_{12}H_{16}O_3$	Asarone(s)[49](Propenyl-2,4,5-trimethoxybenzene).	208.13	58	1,576.2	6,596.4	1,575.9	196.
$C_{12}H_{18}O$	Thymolethyl ether	178.14	64	1,679.9	7,030.4	1,679.7	203.
$C_{16}H_{16}O_2$	Di-p-methoxystilbene (s)	240.14	76	2,016.6	8,433.4	2,018.8	104.
$C_{21}H_{16}O_2$	β-Naphtholformal (s)	300.13	96	2,500.5	10,457.1	2,513.8	60.
$C_{22}H_{18}O$	Methyl ether of diphenylphenylethinyl carbinol.[50]	298.14	104	2,739.4	11,456.2	2,748.3	95.
$C_{23}H_{20}O$	Ethyl ether of diphenylphenylethinyl carbinol.	312.16	110	2,891.4	12,091.8	2,904.6	95.
$C_{24}H_{22}O$	Propyl ether of diphenylphenylethinyl carbinol.	326.17	116	3,047.5	12,744.7	3,060.9	95.

[49] $(CH_3O)_3(^{2,4,5})(C_6H_2)(CH=CH.CH_3)(^1)$.
[50] $(C_6H_5)_2.C(OCH_3)C\equiv C.C_6H_5$.

21. ETHYLENE OXIDES

(α-Oxides)

C_2H_4O	Ethylene oxide (v)	44.03	10	308.4	1,290.7		16; cf. 223.
	Ethylene oxide			302.1	1,264.3		16.
C_3H_6O	α-Propylene oxide [51]	58.05	16	451.1	1,887.9		245.
$C_5H_{10}O$	β-Methyl-β, γ-butene oxide (α-Dimethyltrimethylene oxide).[52]	86.08	28	749.8	3,137.9		245.
$C_6H_{12}O$	γ,δ-Hexylene oxide [53]	100.10	34	913.9	3,824.7		245.
C_9H_8O	Indene oxide	132.06	42	1,116.8	4,673.8		236.

[51] $CH_2.\underset{O}{\overset{H}{C}}-CH_3$.

[52] $(CH_3)_2C-\underset{O}{\overset{H}{C}}-CH_3$.

[53] $CH_3.CH_2.\underset{O}{\overset{H}{C}}-\overset{H}{C}-CH_2.CH_3$.

22. ALIPHATIC ALDEHYDES

[Also those aromatic aldehydes in which the aldehyde group is not attached to the aromatic nucleus]

$Q = 26.05 \times N + 13.0$

CH_2O	Formaldehyde (g)	30.02		134.1	561.2		239.
$\frac{1}{n}(CH_2O)_n$	Paraformaldehyde (c)			[54] 122.1	511.0		239; cf. 56.
$\frac{1}{3}(CH_2O)_3$	α-Trioxymethylene (s)			[54] 109.5	458.3		239; cf. 56.
C_2H_4O	Acetaldehyde (v)	44	10	280.5	1,173.1	279.5	223; cf. 39.
C_2H_4O	Acetaldehyde	44.03	10	279.0	1,166.8	273.5	25.
$C_2H_2O_2$	Glyoxal (s)	58.02	6	172.3	720.6	182.3	69.
C_3H_6O	Propionaldehyde (v)	58		438.4	1,833.4	429.8	223.
C_3H_6O	Propionaldehyde	58.05	16	434.2	1,815.8	429.8	25.

[54] No great reliance can be put upon the above values until the exact details of the determinations become available. The information in the article is extremely meager and insufficient.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

22. ALIPHATIC ALDEHYDES—Continued

[Also those aromatic aldehydes in which the aldehyde group is not attached to the aromatic nucleus]

$Q = 26.05 \times N + 13.0$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
C_3H_4O	Acrolein	56.03	14	389.6	1,629.3	390.7	141.
				393.4	1,646.4		238.
$(C_3H_4O)_3$	Metacrolein (s)	168.09		1,168.8	4,891.4		238.
C_4H_6O	Crotonaldehyde	70.05	20	542.1	2,267.1	547.0	117.
C_4H_8O	Isobutyraldehyde (v)	72	22	596.8	2,495.8	586.1	223.
$C_4H_8O_2$	β-Hydroxybutyraldehyde (Aldol).	88.06	20	546.6	2,285.9	540.5	118.
$C_5H_{10}O$	Valeraldehyde	86.08	28	742.0	3,103.0	742.4	113.
$C_5H_4O_2$	Furol (Furfuraldehyde)	96.03	20	559.5	2,339.8		44.
$C_6H_{12}O_3$	Paraldehyde	132.10		812.8	3,399.1		118.
$(C_2H_4O)_3$	Metaldehyde (s)	132.10		805.6	3,371.4		126.
	Metaldehyde			814.0	3,406.6		126.
$C_7H_{14}O$	n-Heptaldehyde (Oenanthol)	114.11	40	1,062.4	4,442.9	1,055.0	110.
C_9H_8O	Phenylpropiolic aldehyde	130.05	40	1,081.0	4,520.7	1,081.6	138.
C_9H_8O	Cinnamic aldehyde	132.06	42	1,112.3	4,655.0	1,113.6	183.
$C_{10}H_{16}O$	Citral (Geranial)	152.13	54	1,437.0	6,019.6	1,445.7	174.

23. AROMATIC ALDEHYDES

$Q = 26.05 \times N + 13 - 3.5a + 3.5m$

C_7H_6O	Benzaldehyde	106.05	32	841.3	3,520.8	843.1	205.
$C_7H_6O_2$	o-Hydroxybenzaldehyde (Salicylaldehyde).	122.05	30	796.0	3,328.9	794.5	62.
$C_7H_6O_2$	p-Hydroxybenzaldehyde (s)	122.05	30	792.7	3,315.0	794.5	62.
$C_7H_6O_2$	m-Hydroxybenzaldehyde (s)	122.05	30	788.7	3,303.9	794.5	163.
$C_8H_8O_3$	Vanillin (s) (3-Methoxy-4-hydroxybenzaldehyde).	152.06	34	914.1	3,825.5	918.2	183.
$C_8H_6O_3$	Piperonal (s) (Methyleneprotocatechuic aldehyde).	150.05	32	870.1	3,641.4	882.1	183.
				870.7	3,647.4		163.
$C_{14}H_{10}O_3$	Disalicylic aldehyde (s)	226.08		1,589.0	6,645.2		157.

24. ALIPHATIC KETONES

[Also those ketones in which the ketone group is not attached to the aromatic nucleus]

$Q = 26.05 \times N + 6.5$

C_3H_6O	Acetone (v)	58	16	435.8	1,822.5		223.
C_3H_6O	Acetone	58.05	16	430.8	1,801.2	423.3	64.
				426.8	1,784.9		59.
C_4H_8O	Methyl ethyl ketone	72.06	22	582.3	2,435.2	579.6	215.
$C_4H_6O_2$	Diacetyl [55]	86.05	18	503.3	2,104.8		94.
$C_5H_8O_3$	Acetylacetone [56]	100.06	24	[57] 615.9	2,575.7	638.2	78.
$C_5H_{10}O$	Diethyl ketone	86.08	28	735.6	3,076.3	735.6	215; cf. 116.
$C_5H_{10}O$	Methyl propyl ketone (v)	86	28	750.4	3,138.2		223.
$C_5H_{10}O$	Methyl propyl ketone	86.08	28	735.6	3,076.3	735.6	215.
$C_5H_{10}O$	Methyl isopropyl ketone	86.08	28	733.9	3,069.2	735.6	215.
$C_6H_{10}O$	Ethyl allyl ketone	98.08	32	857.1	3,590.4	853.1	162.
$C_6H_{10}O$	Mesityl oxide	98.08	32	846.7	3,543.4	853.1	117.
$C_6H_{10}O$	Allylacetone	98.08	32	856.7	3,588.7	866.1	162.
$C_6H_{10}O_2$	Methylacetylacetone	114.08	30	798.5	3,341.7	794.5	166.
	After several distillations			792.6	3,317.0		
$C_6H_{12}O$	Pinacolin (s) (Methyl *tert.*-butyl ketone).	100.10	34	891.8	3,729.5	892.2	215.
$C_6H_{12}O$	Methyl butyl ketone	100.10	34	895.2	3,743.7	892.2	215.

[55] The author (94) gives only the final value for this compound, and no other information. The values of this observer are about 0.5 per cent too low.

[56] See also p. 382 for *O*-methyl and ethyl ethers.

[57] Evidently this value by (78) is too low. Compare the rather good agreement in the case of the methylacetylacetone.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

24. ALIPHATIC KETONES—Continued

[Also those ketones in which the ketone group is not attached to the aromatic nucleus]

$Q = 26.05 \times N + 6.5$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_7H_{14}O$	Dipropyl ketone	114.11	40	1,050.5	4,393.2	1,048.5	215; cf. 116.
$C_7H_{14}O$	Diisopropyl ketone	114.11	40	1,045.5	4,372.3	1,048.5	116.
$C_8H_{16}O$	Methyl hexyl ketone	128.13	46	1,205.1	5,039.7	1,204.8	215.
$C_9H_{14}O$	Diallylacetone	138.11	48	1,280.7	5,364.8	1,282.9	171.
$C_{10}H_8O_4$	Furil (s)	190.05	38	1,064.4	4,454.5		8.
$C_{10}H_8O$	Acetylphenylacetylene	144.06	46	1,235.0	5,164.8	1,231.4	138.
$C_{10}H_8O_4$	Furoin (s)	192.06	40	1,097.7 1,114.0	4,598.1 4,662.1		241. 8.
$C_{10}H_{10}O$	Benzalacetone (s)	146.08	48	1,257.4	5,262.2	1,266.4	183.
$C_{11}H_{10}O$	Propionylphenylacetylene [58]	158.08	52	1,385.5	5,794.2	1,387.7	138.
$C_{11}H_{12}O$	α-Methyl-α-benzalacetone	160.10	54	1,417.7	5,933.1	1,419.7	166.
$C_{11}H_{12}O$	α-Methyl-α-benzalacetone (s).	160.10	54	1,413.5	5,915.5	1,419.7	166.
$C_{13}H_{12}O$	Butyrylphenylacetylene	172.10	58	[58] 1,537.9	6,431.5	1,544.0	138.
$C_{12}H_{14}O$	Propionylphenybutine [59]	186.11	64	1,686.4	7,052.5	1,703.3	138.
$C_{13}H_{14}O$	Isovalerylphenylacetylene	186.11	64	[58,60] 1,720.5	7,195.1	1,700.3	138.
$C_{13}H_{20}O$	ψ-Ionone	192.16	70	1,851.2	7,754.7	1,868.5	162.
$C_{14}H_{16}O$	Caproylphenylacetylene	200.13	70	[58] 1,833.4	7,667.3	1,856.6	138.
$C_{17}H_{14}O$	Dibenzalacetone (s)	234.11	80	2,087.9	8,737.9	2,103.5	183.

[58] The experimental values of the compounds marked show such wide variations for members of an homologous series that undoubtedly it is the fault of the experimenter. The difficulties of obtaining these substances in pure condition may have had something to do with it. Consult original paper.

[59] $C_6H_5.CH_2CH_2.C{\equiv}C-COC_2H_5$.

[60] The author (138) claims that this compound behaves abnormally in many respects.

25. AROMATIC KETONES

$Q = 26.05 \times N + 6.5 - 3.5a - 6.5b$

C_8H_8O	Acetophenone (s)	120.06	38	988.9	4,138.6	992.9	183.
$C_{13}H_{10}O$	Benzophenone (s)	182.08	60	1,556.5	6,514.4	1,562.5	206; cf. 183, 95.
$C_{14}H_{10}O_2$	Benzil (s)	210.08	62	1,624.6	6,798.9	1,627.6	182; cf. 94.
$C_{14}H_{10}O_4$	Benzoyl peroxide (s)	242.08		[61] 1,551.7	6,500.1		163.
$C_{14}H_{12}O_2$	Benzoin (s)	212.10	64	1,671.4	6,994.8	1,673.2	182.
$C_{15}H_{10}O$	Benzoylphenylacetylene (s)	206.08	68	1,787.2	7,474.1	1,801.0	138.
$C_{21}H_{16}O$	β-Phenylbenzalacetophenone.[62]	284.12	98	2,545.3	10,644.4	2,555.9	95.
$C_{21}H_{18}O_2$	β,β-Diphenyl-β-hydroxypropiophenone.	302.15	98	2,538.0	10,613.9	2,555.4	95.

[61] Compare W. A. Roth and R. Lasse, Z. Electrochem., **30**, p. 607; 1924. These authors, using a microcombustion apparatus, obtained values for this substance which varied within 2 per cent. This discrepancy is due to the fact that the substance does not burn completely and always leaves varying amounts of unburned carbon.

[62] $(C_6H_5)_2{:}C{:}C(H)-C(=O)-C_6H_5$.

26. QUINONES

$Q = 26.05 \times N + 33.1 - 3.5a - 6.5b$

$C_6H_4O_2$	Quinone (s) [63]	108.03	24	656.3 656.6	2,746.6 2,747.9	658.3	225. 180; cf. 30, 43, 222.
$C_7H_8O_2$	Toluquinone (s)	122.05	30	803.2	3,361.4	811.1	225; cf. 222.
$C_{10}H_6O_2$	α-Naphthoquinone (s)	158.05	42	1,100.8	4,606.9	1,114.2	225; cf. 222.
$C_{10}H_6O_2$	β-Naphthoquinone (s)	158.05	42	1,105.4	4,630.3	1,114.2	225; cf. 222.
$C_{10}H_{12}O_2$	Thymoquinone (s)	164.10	48	1,271.3	5,320.4	1,276.5	225; cf. 222.
$C_{14}H_8O_2$	Anthraquinone (s)	208.06	60	1,544.5	6,463.7	1,562.0	225; cf. 222.
$C_{14}H_8O_2$	Phenanthraquinone (s)	208.06	60	1,544.0	6,461.6	1,562.5	225; cf. 222.
$C_{14}H_8O_3$	Monohydroxyanthraquinone (s).	224.06	58	1,481.7	6,200.9	1,513.4	225; cf. 222.

[63] The heat of combustion of quinhydrone is given by (180), Z. Phys. Chem., **117**, p. 57, 1925, as 1,334.5 kg-cal$_{15}$ per mole.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

26. QUINONES—Continued

$Q = 26.05 \times N + 33.1 - 3.5a - 6.5b$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_{14}H_8O_4$	1,2-Dihydroxyanthraquinone (s) (Alizarin).	240.06	56	1,448.9	6,063.6	1,464.8	225; cf. 222.
$C_{14}H_8O_5$	1,2,4-Trihydroxyanthraquinone (Purpurin).	256.06	54	1,402.1	5,867.8	1,416.2	225; cf. 222.
$C_{14}H_8O_8$	1,2,3,5,6,7-Hexahydroxyanthraquinone (s) (Rufigallic acid).	304.06	48	1,249.1	5,227.5	1,268.4	225; cf. 222.
$C_{21}H_{18}O_2$	Retenequinone (s) (Methylisopropylphenanthraquinone).	264.13	84	2,152.4	9,007.8	2,187.7	225; cf. 222.

27. HYDROAROMATIC AND POLYMETHYLENE KETONES

$Q = 26.05 \times N + 6.5$

C_5H_8O	Acetyltrimethylene	84.06	26	691.4	2,891.4	----------	215.
C_5H_8O	Cyclopentanone	84.06	26	682.0	2,852.1	683.8	163.
$C_6H_{10}O$	β-Methylcyclopentanone	98.08	32	[64] 833.4	3,485.3	840.1	215.
$C_6H_{10}O$	Acetylcyclobutane	98.08	32	856.8	3,583.1	----------	215.
$C_6H_{10}O$	3-Methylcyclohexene-2-one-1.	98.08	36	942.9	3,943.2	950.8	149.
$C_7H_{12}O$	Ethyl-1-cyclopentanone-2	112.10	38	990.4	4,141.9	996.4	215.
$C_7H_{12}O$	1,3-Dimethylcyclopentanone-2.	112.10	38	989.8	4,139.3	996.4	215.
$C_7H_{12}O$	β-Methylcyclohexanone	112.10	38	994.8	4,160.3	996.4	215.
$C_7H_{12}O$	Cycloheptanone (Suberone)	112.10	38	996.7	4,168.2	996.4	215.
$C_8H_{12}O$	1,3-Dimethylcyclohexene-6-one-5.	124.10	42	1,102.2	4,609.4	1,107.1	215.
$C_8H_{14}O$	1,1-Dimethylcyclohexanone-2.	126.11	44	1,152.1	4,826.2	1,152.7	163.
C_9H_8O	α-Indanone	132.06	42	1,086.9	4,548.7	1,093.6	236.
C_9H_8O	β-Indanone	132.06	42	1,088.3	4,554.5	1,093.6	236.
$C_9H_{14}O$	1,1,5-Trimethylcyclohexene-5-one-3.	138.11	48	1,248.4	5,220.8	1,263.4	215.
$C_9H_{14}O$	*cis*-β-Hydrindanone	138.11	48	1,248.1	5,223.3	1,256.9	83.
$C_9H_{14}O$	*trans*-β-Hydrindanone	138.11	48	1,243.0	5,202.0	1,256.9	83.
$C_9H_{16}O$	1,4-Methylacetylcyclohexane	140.11	48	1,267.8	5,301.9	1,256.9	215.
$C_9H_{16}O$	Ethylcyclohexyl ketone	140.11	50	1,289.5	5,392.7	1,309.0	215.
$C_9H_{16}O$	Methylcycloheptyl ketone	140.11	50	1,278.3	5,345.9	1,309.0	215.
$C_{10}H_{14}O$	Carvone	150.11	52	1,374.4	5,751.9	1,380.6	201.
$C_{10}H_{14}O$	Eucarvone	150.11	52	1,373.1	5,751.9	1,374.1	175.
$C_{10}H_{18}O$	*cis*-β-Decalone	152.13	54	1,404.4	5,877.4	1,413.2	169.
$C_{10}H_{18}O$	*trans*-β-Decalone	152.13	54	1,402.1	5,867.8	1,413.2	169.
$C_{10}H_{16}O$	Carone	152.13	------	1,397.1	5,842.7	----------	50.
$C_{10}H_{16}O$	Dihydrocarvone	152.13	54	{ 1,412.2 1,423.7	5,905.8 5,958.2	1,426.2 ----------	215. 50; cf. 162.
$C_{10}H_{16}O$	Carvenone	152.13	54	{ 1,407.9 1,417.0	5,897.7 5,930.2	1,419.7 ----------	162. 50.
$C_{10}H_{16}O$	Pulegone	152.13	54	1,412.1	5,915.3	1,426.2	174.
$C_{10}H_{16}O$	Isopulegone	152.13	54	1,416.4	5,933.3	1,426.2	162.
$C_{10}H_{16}O$	Thujone	152.13	54	1,430.4	5,991.9	----------	175.
$C_{10}H_{16}O$	Dihydroeucarvone	152.13	54	[65] 1,427.6	5,974.5	1,419.7	50.
$C_{10}H_{16}O$	Camphor (s)	152.13	54	{ 1,411.0 1,410.8	5,910.7 5,904.2	1,413.2 ----------	125. 217; cf. 175, 183, 70.
$C_{13}H_{20}O$	α-Ionone	192.16	70	1,835.4	7,688.5	1,849.5	174.
$C_{13}H_{20}O$	β-Ionone	192.16	70	1,839.9	7,707.3	1,849.5	174.

[64] The correction of 1 per cent applied to (215) values is evidently too large. Roth recommends about 0.6 per cent.

[65] The author (50) gives values about 0.6 per cent too high.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

28. CARBOHYDRATES (Monosaccharides)

$Q = 26.05 \times N + 13q + 13j + 6.5k + 3.51$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_5H_{10}O_5$	Arabinose (s)	150.08	20	558.0	2,335.2	566.5	195.
				559.9	2,343.2		87; cf. 31.
$C_5H_{10}O_5$	Xylose (s)	150.08	20	561.5	2,350.3	566.5	183.
				560.5	2,345.7		87; cf. 31.
$C_6H_{10}O_5$	Levoglucosan (s)	162.08		677.7	2,836.2		87.
$C_6H_{12}O_5$	Rhamnose (s)	164.10	26	717.9	3,004.4	722.8	195.
				718.3	3,006.1		87.
$C_6H_{12}O_5.H_2O$	Rhamnose (cryst.)	182.11		711.5	2,977.6		195.
$C_6H_{12}O_5$	Fucose (s)	164.10	26	711.9	2,979.3	722.8	195.
$C_6H_{12}O_6$	*d*-Glucose (s) (Dextrose)	180.10	24	673.0	2,816.5	677.2	182; cf. 195, 64, 87.
$C_6H_{12}O_6$	*l*-Fructose (s)	180.10	24	675.6	2,827.4	677.2	195.[66]
				671.0	2,805.5		64.[66]
$C_6H_{12}O_6$	Sorbinose (s) (*d*-Sorbose)	180.10	24	668.3	2,796.8	677.2	195.
$C_6H_{12}O_6$	Galactose (s)	180.10	24	669.5	2,801.9	677.2	195.
				670.7	2,806.9		87; cf. 48.
$C_7H_{14}O_7$	Glucoheptose (s)	210.11	28	783.5	3,276.6	787.9	68.
$C_{12}H_{18}O_9$	Rhamnose triacetate (s)[67]	290.14	50	1,350.5	5,647.8	1,354.5	87.
$C_{16}H_{22}O_{11}$	Pentaacetylglucose (s)	390.17	64	1,726.3	7,219.4	1,725.7	87.[66]
$C_{16}H_{22}O_{11}$	Pentaacetylgalactose (s)	390.17	64	1,725.5	7,216.0	1,725.7	87.

[66] The heat of combustion of benzoic acid obtained by these investigators is about 0.2 per cent higher than the present international value. Their results are therefore uniformly too high.

[67] For the method of calculating these compounds, consult the formula for esters.

29. DISACCHARIDES

$Q = 26.05 \times N + 19.5o + 13j + 6.5k + 3.51 + 13q$

$C_{12}H_{22}O_{11}$	Cane sugar (s) (Sucrose)	342.18	48	1,349.6	5,648.3		230.5; cf. 80, 67, 52, 237, 9, 172, 5, 241, 195, 224, 153, 87.
$C_{12}H_{22}O_{11}$	Milk sugar (anhydr.) (s) (Lactose).			1,350.8	5,653.1		195; cf. 87, 181,[66] 74, 88.
$C_{12}H_{22}O_{11}.H_2O$	Lactose (cryst.) (s)	360.19		1,344.7	5,627.6		195; cf. 64, 150, 46.
$C_{12}H_{22}O_{11}$	Maltose (s)	342.18		1,350.2	5,649.8		195.
				1,351.3	5,655.2		87.
$C_{12}H_{22}O_{11}.H_2O$	Maltose (cryst.)	360.19		1,339.2	5,604.6		195; cf. 64.
$C_{12}H_{22}O_{11}$	Trehalose (s) (Mycose)	342.18		1,349.4	5,647.2		183.
$C_{12}H_{22}O_{11}.2H_2O$	Trehalose (cryst.)	378.21		1,341.5	5,614.2		183.
$C_{12}H_{22}O_{11}$	Cellobiose (s) (anhydr.)	342.18		1,349.9	5,649.3		87.
$C_{28}H_{38}O_{19}$	Sucrose octaacetate (s)	678.3		3,033.3	12,694.4		87.
$C_{28}H_{38}O_{19}$	Maltose octaacetate (s)	678.3		3,030.6	12,683.1		87.
$C_{28}H_{38}O_{19}$	Cellobiose octaacetate (s)	678.3		3,032.6	12,691.5		87.
$C_{28}H_{38}O_{19}$	Lactose octaacetate (s)	678.3		3,029.3	12,677.7		87.

[66] The author (181) used the potassium chlorate method. The value is unreliable.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

30. TRI, TETRA, AND POLYSACCHARIDES

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_{18}H_{32}O_{16}$	Raffinose (s) (Melitose)	504.26		2,025.5	8,476.7		195; cf. 31.
$C_{18}H_{32}O_{16}.5H_2O$	Raffinose (cryst.)	594.34		2,018.9	8,449.1		195.
$C_{18}H_{32}O_{16}.H_2O$	Melezitose (s)	522.28		2,042.0	8,545.8		195.
$C_{24}H_{42}O_{21}$	Stachyose (anhydrous) (s) calc.	664.34		2,708.7	11,335.9		87.
	Starch			4,178.8	17,488.3		195.[69]
	Starch acetate			4,499.0	18,828.3		87.
	Inulin			4,129.9	17,283.6		195.
				4,190.0	17,535.2		87.
	Inulin acetate			4,522	18,924.6		87.
	Dextrin			4,107.9	17,191.6		195.
	Glycogen [69]			4,186.8	17,521.8		207; cf. 64, 75, 133.
	Cellulose			4,180.8	17,496.6		195; cf. 76.
	Cellulose acetate			4,496.0	18,815.8		87.
	Xylan			[70] 4,243.0	17,756.9		87.
	Xylan acetate			4,548.0	19,033.4		87.[71]

[69] W. K. Slater gives as the heat of combustion of the dry monohydrate $C_6H_{10}O_5.H_2O$, 3,836×4.182 joules per gram; Biochem. J., 18, p. 629; 1924. The authors (133), on the other hand, report the following values of the mean heats of combustion of glycogen from *Mytilus* and from frog muscle, per gram: Anhydrous glycogen, 4,238; hydrate 4,214; dissolved glycogen, 4,202.

[70] More probable value, 4,260.0

[71] These authors also give the values for diamylose, α-tetramylose, β-hexamylose, α-octamylose.

31. ALIPHATIC ACIDS [72]

(Saturated monobasic)

$$Q = 26.05 \times N$$

CH_2O_2	Formic acid [73]	46.02	2	62.8	262.6	65.1	34, 86.
	Formic acid (liq. at 0°)			[74] 62.6	261.8		223.
$C_2H_4O_2$	Acetic acid	60.03	8	209.4	875.7	208.4	34.
				207.1	866.7		164.
$C_3H_6O_2$	Propionic acid	74.05	14	367.2	1,536.7	364.7	192; cf. 118.
$C_4H_8O_2$	n-Butyric acid	88.06	20	524.3	2,194.2	521.0	192; cf. 77.
$C_4H_8O_2$	Isobutyric acid	88.06	20	517.4	2,163.8	521.0	117.
$C_5H_{10}O_2$	n-Valeric acid	102.08	26	681.6	2,852.5	677.3	192.
$C_6H_{12}O_2$	Caproic acid	116.10	32	831.0	3,475.2	833.6	215.
				838.2	3,511.2		66; cf. 115.
$C_6H_{12}O_2$	Isobutylacetic acid	116.10	32	837.4	3,504.5	833.6	192.
$C_6H_{12}O_2$	Diethylacetic acid	116.10	32	830.8	3,474.4	833.6	227.
				837.4	3,504.5		192.
$C_7H_{14}O_2$	Ethylpropylacetic acid	130.11	38	994.5	4,161.9	989.9	192.
$C_7H_{14}O_2$	Heptylic acid	130.11	38	986.1	4,123.9	989.9	227.
$C_8H_{16}O_2$	Dipropylacetic acid	144.13	44	1,151.6	4,819.4	1,146.2	192.
$C_9H_{18}O_2$	Heptylacetic acid	158.14	50	1,309.4	5,479.8	1,302.5	192.
				1,287.4	5,383.9		120.
$C_{10}H_{20}O_2$	Capric acid (s)	172.16	56	1,458.1	6,102.1	1,458.8	192.
$C_{11}H_{22}O_2$	Undecylic acid (s)	186.18	62	1,615.9	6,762.5	1,615.1	192.
$C_{12}H_{24}O_2$	Lauric acid (s)	200.19	68	1,771.7	7,414.6	1,771.4	193.
$C_{14}H_{28}O_2$	Myristic acid (s)	228.22	80	2,085.8	8,729.0	2,084.0	193.
$C_{16}H_{32}O_2$	Palmitic acid (s)	256.26	92	2,398.4	10,037.3	2,396.6	192.[74a]
				2,384.6	9,970.0		64.[74b]
$C_{18}H_{36}O_2$	Stearic acid (s)	284.29	104	[75] 2,711.8	11,348.9	2,709.2	192.
				2,697.7	11,279.0		64.
$C_{20}H_{40}O_2$	Arachidic acid (s)	312.32	116	3,025.9	12,663.4	3,021.8	192.
$C_{22}H_{44}O_2$	Behenic acid (s)	340.35	128	3,338.4	13,971.2	3,334.4	193.

[72] The values of (192) are uniformly about 0.5 to 0.7 per cent higher than the values for the same compounds recorded by modern investigators.

[73] The formula for formic and oxalic acids is $Q = 26.05 \times N + 13$.

[74] This value is calculated from Thomsen's data. The figure is more or less uncertain, for the specific heat value (4.77 cal.) varies considerably with the temperature.

[74a] See footnote 72.

[74b] The values of (64) are uniformly 0.2 per cent high, for the value they employed for benzoic acid was larger than the accepted one by that amount.

[75] See footnote 72.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

32. ALIPHATIC ACIDS

(Hydroxy and Keto Acids)

$Q = 26.05 \times N + 6.5s + 13j + 6.5k + 3.5l + 13u + 6.5v + 6.5w$

Formula	Name	Molecular weight	Number of electrons	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_2H_2O_3.H_2O$	Dihydroxyacetic acid (s) (Glyoxylic acid).	92.03	4	[76] 125.5	524.8	130.2	35.
$C_2H_4O_3$	Glycollic acid (s)	76.03	6	166.6	697.2	169.3	182.
$C_3H_4O_3$	Pyroracemic acid	88.03	10	279.1	1,168.0	280.5	49.
$C_3H_6O_3$	Lactic acid (s)	90.05	12	[77] 326.0	1,363.0	325.6	64; cf. 127, 135, 75, 134.[78]
$C_4H_8O_3$	Hydroxyisobutyric acid (s)	104.06	18	471.8	1,973.1	481.9	134; cf. 127.
$C_4H_8O_3$	β-Hydroxybutyric acid (s) (Racemic).	104.06	18	487.9	2,039.9	475.4	64.
$C_5H_4O_3$	Pyromucic acid (s)	112.03	------	489.7	2,049.4	----------	182; cf. 44.
$C_5H_8O_3$	Levulinic acid (s) (β-Acetopropionic acid).	116.06	22	576.8	2,412.2	579.6	18.
$C_{22}H_{44}O_4$	Dihydroxybehenic acid (s)	372.35	124	3,235.7	13,541.4	3,243.2	193.

[76] See method of calculation for formic and oxalic acids, footnote 73.
[77] This value was obtained by burning a concentrated solution of lactic acid and analyzing the same for carbon and hydrogen.
[78] The value was obtained by burning the ethyl and methyl esters of lactic acid.

33. ALIPHATIC ACIDS (UNSATURATED)

$Q = 26.05 \times N + 13$

$C_3H_4O_2$	Acrylic acid	73.02	12	[79] 327.5	1,369.6	325.6	140; cf. 155.
$C_4H_6O_2$	Crotonic acid (s)	86.05	18	477.7	1,999.2	481.9	183.
$C_5H_8O_2$	Tiglic acid (s)	100.06	24	626.4	2,621.5	631.7	183.
$C_5H_8O_2$	Angelic acid (s)	100.06	24	[80] 634.8	2,656.6	638.2	183.
$C_5H_8O_2$	α-β-Pentenoic acid (s)	100.06	24	623.7	2,610.2	638.2	166.
$C_5H_8O_2$	β-γ-Pentenoic acid (s)	100.06	24	632.2	2,645.8	638.2	166.
$C_5H_8O_2$	Allylacetic acid	100.06	24	641.6	2,685.1	638.2	167.
$C_6H_8O_2$	Sorbic acid (s)	112.06	28	743.0	3,109.5	755.4	183.
$C_6H_{10}O_2$	Hydrosorbic acid	114.08	30	795.4	3,331.9	794.5	66.
$C_{10}H_{16}O_2$	Geranic acid	168.13	52	1,379.0	5,776.7	1,380.6	171.
$C_{11}H_{20}O_2$	Undecylenic acid (s)	184.16	60	[81] 1,579.7	6,611.0	1,576.0	183.
$C_{18}H_{34}O_2$	Oleic acid	282.27	102	{ 2,657.0 2,681.8	11,108.9 11,223.3	2,663.6 ----------	64. 183.
$C_{18}H_{34}O_2$	Elaidic acid (s)	282.27	102	2,664.2	11,149.7	2,670.1	183.
$C_{22}H_{42}O_2$	Brassidic acid (s)	338.34	126	3,290.1	13,769.1	3,288.8	193.
$C_{22}H_{42}O_2$	Erucic acid (s)	338.34	126	3,296.7	13,796.7	3,295.3	193.

[79] The above is the mean of two determinations which do not agree better than 0.4 per cent.
[80] For method of calculating *cis-trans* isomers, consult formula for maleic acid.
[81] Mean value.

34. ALIPHATIC ACIDS (MONOBASIC)

(Acetylene type)

$Q = 26.05 \times N + 33.1h$

$C_4H_4O_2$	Tetrolic acid (s)	84.03	16	452.4	1,893.3	449.9	183.
$C_8H_{12}O_2$	Amylpropiolic acid	140.09	40	1,083.0	4,529.1	1,075.1	138.
$C_9H_{14}O_2$	Hexylpropiolic acid	154.11	46	1,231.8	5,151.4	1,231.4	138.
$C_{11}H_{18}O_2$	Undecolic acid(s)	182.14	58	1,537.8	6,435.7	1,544.0	183.
$C_{18}H_{32}O_2$	Stearolic acid (s)	280.26	100	2,628.6	11,000.7	2,638.1	183.
$C_{22}H_{40}O_2$	Behenolic acid (s)	336.32	124	3,254.9	13,621.8	3,263.3	193.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

35. ALIPHATIC ACIDS (POLYBASIC SATURATED)

$Q = 26.05 \times N$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_2H_2O_4$	Oxalic acid (s)	90.02	2	60.2	251.9	[83] 65.1	190.
				60.1	251.5		235; cf. 86.
$C_3H_4O_4$	Malonic acid (s)	104.03	8	207.2	8,671.3	208.4	190.
				206.5	8,642.0		235; cf. 127, 121, 123.
$C_4H_6O_4$	Succinic acid (s)	118.05	14	356.6	1,492.4	364.7	190.
				357.1	1,494.5		235; cf. 123, 127.
$C_4H_6O_4$	Methylmalonic acid (s)	118.05	14	362.2	1,515.8	364.7	192.
				365.0	1,527.5		190.
$C_5H_8O_4$	Glutaric acid (s)	132.06	20	514.7	2,154.0	521.0	186.
				514.9	2,154.9		235; cf. 129.
$C_5H_8O_4$	Methylsuccinic acid (s)	132.06	20	514.9	2,154.9	521.0	190.
				515.7	2,158.2		234; cf. 127.
$C_5H_8O_4$	Ethylmalonic acid (s)	132.06	20	517.7	2,166.6	521.0	190.
$C_5H_8O_4$	Dimethylmalonic acid (s)	132.06	20	515.1	2,155.7	521.0	190.
$C_6H_6O_6$	Tricarballylic acid (s)	170.06	20	516.0	2,159.5	521.0	127; cf. 192.
$C_6H_{10}O_4$	Adipic acid (s)	146.08	26	668.6	2,798.1	677.3	190.
				669.0	2,799.8		235.
$C_6H_{10}O_4$	α-Methylglutaric acid (s)	146.08	26	670.6	2,806.5	677.3	190.
$C_6H_{10}O_4$	Ethylsuccinic acid (s)	146.08	26	671.9	2,811.9	677.3	190.
				670.6	2,806.5		234.
$C_6H_{10}O_4$	*Sym.* Dimethylsuccinic acid (s) (*para*-acid).	146.08	26	670.6	2,806.5	677.3	190.
$C_6H_{10}O_4$	*Sym.* Dimethylsuccinic acid (s) (*anti*-acid).	146.08	26	674.2	2,821.5		183.
$C_6H_{10}O_4$	*Sym.* Dimethylsuccinic acid (s) (M. P. 128°) (Racemic).	146.08	26	671.5	2,810.2	677.3	234.
$C_6H_{10}O_4$	*Sym.* Dimethylsuccinic acid (s) (M. P. 208°) (*anti*).	146.08	26	673.0	2,816.5	677.3	234.
$C_6H_{10}O_4$	*Unsym.* Dimethylsuccinic acid (s).	146.08	26	671.4	2,809.8	677.3	190.
				670.6	2,806.5		234.
$C_6H_{10}O_4$	Methylethylmalonic acid (s)	146.08	26	671.9	2,811.9	677.3	190.
				[82] 675.6	2,827.4		192.
$C_6H_{10}O_4$	Propylmalonic acid (s)	146.08	26	[83] 676.1	2,829.5	677.3	192.
$C_6H_{10}O_4$	Isopropylmalonic acid (s)	146.08	26	[83] 676.1	2,829.5	677.3	192.
$C_7H_{12}O_4$	Pimelic acid (s) (Isopropylsuccinic acid).	160.04	32	822.3	3,441.3	833.6	190.
				827.5	3,463.0		187.
				827.7	3,463.9		235.
$C_7H_{12}O_4$	Diethylmalonic acid (s)	160.10	32	[83] 832.6	3,484.4	833.6	192.
$C_7H_{12}O_4$	Trimethylsuccinic acid (s)	160.10	32	829.9	3,473.1	833.6	234.
$C_8H_{14}O_4$	Suberic acid (s)	174.11	38	985.2	4,123.0	989.9	190.
				983.3	4,115.1		187.
				983.4	4,115.5		235; cf. 127.
$C_8H_{14}O_4$	Dimethyladipic acid (s) (*sym.*).	174.11	38	986.7	4,129.3	989.9	182.
$C_8H_{14}O_4$	Diethylsuccinic acid (s) (*unsym.*).	174.11	38	984.6	4,120.6	989.9	234.
$C_8H_{14}O_4$	Diethylsuccinic acid (s) (*sym.*) (M. P. 128°).	174.11	38	986.1	4,126.8	989.9	234.
$C_8H_{14}O_4$	Diethylsuccinic acid (s) (sym.) (M. P. 192°).	174.11	38	987.8	4,133.9	989.9	234.
$C_8H_{14}O_4$	Ethylpropylmalonic acid (s)	174.11	38	[84] 988.5	4,136.9	989.9	192.
$C_8H_{14}O_4$	Tetramethylsuccinic acid (s)	174.11	38	989.4	4,140.6	989.9	234.
$C_9H_{16}O_4$	Azelaic acid (s)	188.13	44	1,141.0	4,775.1	1,146.2	191.
				1,141.7	4,778.0		235.
$C_9H_{16}O_4$	Dipropylmalonic acid (s)	188.13	44	[83] 1,145.8	4,795.2	1,146.2	192.

[83] The calculated heats of combustion for compounds in which 2 weakly electronegative groups, such as COOH, are linked together, is given by the expression $Q = 26.05 \times N + 13$. The correction factor thus denotes that the two carbon atoms share a pair of valence electrons in outer energy levels, compared to a carbon-to-carbon linkage as in ethane.

[82] The values of (192) are on the whole about 0.5 to 0.7 per cent too high.

[84] See footnote 83.

[83] See footnote 83.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

35. ALIPHATIC ACIDS (POLYBASIC SATURATED)—Continued

$Q = 26.05 \times N$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_{10}H_{18}O_4$	Sebacic acid (s)	200.14	50	1,296.4 1,297.3	5,425.4 5,429.2	1,302.5	191. 235; cf. 127.
$C_{10}H_{18}O_4$	Heptylmalonic acid (s)	200.14	50	[85] 1,302.4	5,450.5	1,302.5	192.
$C_{10}H_{18}O_4$	Triethylsuccinic acid (s)	200.14	50	1,301.3	5,445.9	1,302.5	234.
$C_{11}H_{20}O_4$	*n*-Octylmalonic acid (s)	216.16	56	[85] 1,458.1	6,102.1	1,458.8	192.
$C_{11}H_{20}O_4$	Nonanedicarboxylic acid (s)	216.16	56	1,455.6	6,091.7	1,458.8	235.
$C_{12}H_{22}O_4$	Decanedicarboxylic acid (s)	230.18	62	1,610.7	6,740.8	1,615.1	235.
$C_{12}H_{22}O_4$	Tetraethylsuccinic acid (s)	230.18	62	1,618.8	6,774.6	1,615.1	235.
$C_{13}H_{24}O_4$	Brassylic acid (s) (Undecanedicarboxylic acid).	244.19	68	1,768.6	7,401.6	1,771.4	235.
$C_{19}H_{38}O_4$	Cetylmalonic acid (s)	328.29	104	[86] 2,707.3	11,330.0	2,709.2	192.

[85] See footnote 83.

[86] See footnote 83.

36. HYDROXY POLYBASIC ACIDS (SATURATED)

$Q = 26.05 \times N + 6.5k + 6.5v$

$C_3H_4O_5$	Tartronic acid (s)	120.03	6	165.4	691.7	175.8	130.
$C_3H_4O_6$	Mesoxalic acid (s) (Dihydroxymalonic acid).	136.03	4	128.2	536.1	136.7	130.
$C_4H_6O_5$	*l*-Malic acid (s)	134.05	12	320.1	1,339.6	325.6	75.
$C_4H_6O_6$	*d*-Tartaric acid (s)	150.05	10	275.1	1,151.29	286.5	54; cf. 29.
$C_4H_6O_6$	*d*, *l*-Tartaric acid (s) (Racemic; anhydr.).	150.05	10	278.4 273.0	1,164.3 1,142.5	286.5	145.[86a] 54.
$C_4H_6O_6$	*d*, *l*-Tartaric acid (s) (Racemic; cryst.).	150.05	10	277.8	1,161.8	286.5	145.
$C_4H_6O_6$	Mesotartaric acid (s) [87]	150.05	10	276.0	1,155.1	286.5	54.
$C_5H_8O_7$	Trihydroxyglutaric acid (s)	180.06	14	388.3	1,623.9	397.2	68.
$C_6H_{10}O_8$	Mucic acid (s)	210.08	18	483.6	2,023.9		183.
$C_6H_{10}O_8$	Allomucic acid (s)	210.08	18	494.2	2,066.7	507.9	68.
$C_6H_8O_7$	Citric acid (s) (anhydr.)	192.06	18	474.5	1,985.8	488.4	191; cf. 127.
$C_6H_8O_7 \cdot H_2O$	Citric acid (s) (cryst.)	210.08	18	471.4	1,971.4		127.
$C_8H_{14}O_6$	Dimethyldihydroxyadipic acid (s).	206.11	34	889.0	3,717.8	898.7	243.

[86a] Little value should be attached to the work of this investigator. The results are probably not better than 1 to 2 per cent and are too high.

[87] The authors (54) give also the heat of combustion of various ammonium and substituted ammonium salts of *d*-tartaric, racemic and mesotartaric acids:

	Kg-cal$_{15}$	K. J.		Kg-cal$_{15}$	K. J.
1. Ammonium *d*-bitartrate	341.7	1,430.0	7. Ethylammonium biracemate	663.1	2,775.1
2. Ammonium biracemate	339.5	1,420.8	8. Phenylammonium *d*-bitartrate	1,079.3	4,516.9
3. Ammonium bimesotartrate	341.2	1,427.9	9. Phenylammonium biracemate	1,077.3	4,508.5
4. Methylammonium *d*-bitartrate	508.0	2,126.0	10. Benzylammonium biracemate	1,229.9	5,147.1
5. Methylammonium biracemate	506.0	2,117.6	11. Benzylammonium bimesotartrate	1,231.5	5,153.8
6. Ethylammonium *d*-bitartrate	665.4	2,784.7			

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

37. POLYBASIC ALIPHATIC ACIDS (UNSATURATED)

$Q = 26.05 \times N + 13y + 16.5x$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_4H_4O_4$	Fumaric acid (s) [88] (*trans*)	116.03	12	320.0	1,339.2	325.6	190; cf. 163, 127, 146.
$C_4H_4O_4$	Maleic acid (s) (*cis*)	116.03	12	326.1	1,364.7	329.1	190; cf. 127, 151.
$C_5H_6O_4$	Itaconic acid (s) (Methylenesuccinic acid).	130.05	18	475.6 475.0	1,990.4 1,987.9	481.9	183. 151; cf. 127.
$C_5H_6O_4$	Citraconic acid (s) (methylmaleic acid) (*cis*).	130.05	18	479.4 478.8	2,006.2 2,003.8	485.4	183. 151; cf. 127.
$C_5H_6O_4$	Mesaconic acid (s) (Methylfumaric acid) (*trans*).	130.05	18	476.9 475.9	1,995.8 1,991.6	481.9	183. 151; cf. 127.
$C_6H_6O_6$	Aconitic acid (s)	174.05	18	475.1	1,988.3	481.9	183; cf. 127.
$C_6H_8O_4$	α,β-Hydromuconic acid (s)	144.06	24	628.8	2,631.5	638.2	183.
$C_6H_8O_4$	β,γ-Hydromuconic acid (s)	144.06	24	629.1	2,632.8	638.2	183.
$C_6H_8O_4$	Allylmalonic acid (s)	144.06	24	[89] 637.8	2,669.2	638.2	192.
$C_7H_{10}O_4$	Teraconic acid (s) (γ-Dimethylitaconic acid).	158.08	30	796.1	3,331.7	794.5	145.
$C_4H_2O_4$	Acetylenedicarboxylic acid (s).	114.02	10	305.9	1,280.2		183.

[88] A collection of the heats of combustion of some stereoisomeric acids is given by Liebermann, Ber., **25**, p. 90; 1892.

[89] The values of (192) are from 0.5 to 0.7 per cent too high.

38. AROMATIC ACIDS

$Q = 26.05 \times N - 3.5a - 6.5b$

$C_7H_6O_2$	Benzoic acid (s) [90]	122.05	30	[90] 771.2	3,227.5	778.0	63; cf. 191, 153, 80, 221, 227, 241, 67, 85, 84, 216, 228, 71, 159, 213, 219, 220, 218, 214.
$C_8H_8O_2$	*o*-Toluic acid (s)	136.08	36	928.9 921.0	3,887.5 3,858.1	930.8	189. 5.
$C_8H_8O_2$	*m*-Toluic acid (s)	136.08	36	928.6 922.2	3,886.2 3,863.1	930.8	189. 5.
$C_8H_8O_2$	*p*-Toluic acid (s)	136.08	36	926.9	3,879.1	930.8	189.
$C_9H_8O_3$	*o*-Oxymethylbenzoic acid (s)	152.06	34	887.3	3,713.4	891.7	199.
$C_9H_8O_3$	*o*-Acetylbenzoic acid (s)	164.06	38				151.
$C_9H_8O_3$	*m*-Acetylbenzoic acid (s)	164.06	38				151.
$C_9H_8O_3$	*p*-Acetylbenzoic acid (s)	164.06	38				151.
$C_9H_{10}O_2$	Mesitylenic acid (s)	150.08	42	1,084.7	4,539.5	1,083.6	189.
$C_{10}H_{12}O_2$	Cuminic acid (s) (*p*-Isopropylbenzoic acid).	164.10	48	1,238.1	5,181.5	1,243.4	189; cf. 30.
$C_{11}H_8O_2$	α-Naphthoic acid (s)	172.06	48	1,231.8	5,155.1	1,233.9	190.
$C_{11}H_8O_2$	β-Naphthoic acid (s)	172.06	48	1,227.6	5,137.5	1,233.9	189.

[90] The above value is the one accepted at the third conference of the International Union of Pure and Applied Chemistry, held at Lyons, 1923. It is the value found by Dickinson, Bull. Bur. Stds., **11**, p. 189; 1915. See also discussion of Verkade in Chem. Weekblad, **19**, p. 389; 1922.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

39. HYDROXY AROMATIC ACIDS

$Q = 26.05 \times N + 3.5m - 3.5a - 6.5b$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_7H_6O_3$	Salicylic acid (s)	138.05	28	[91] 723.1	3,026.2	729.4	230.
				723.6	3,028.3		217.
				726.7	3,041.2		198.
				[92] 723.8	3,032.0		89; cf. 62, 189.
$C_7H_6O_3$	*m*-Hydroxybenzoic acid (s)	138.05	28	726.1	3,038.7	729.4	199.
				724.7	3,032.9		89; cf. 189.
$C_7H_6O_3$	*p*-Hydroxybenzoic acid (s)	138.05	28	725.4	3,035.8	729.4	189.
				723.8	3,029.1		89.
$C_7H_6O_4$	β-Resorcylic acid (s) (2,4-Dihydroxybenzoic acid).	154.05	26	676.5	2,831.2	680.8	189.
$C_7H_6O_5$	Pyrogallolcarboxylic acid (s)	170.05	24	633.4	2,650.8	632.2	189.
$C_7H_6O_5$	Gallic acid (s)	170.05	24	633.7	2,652.0	632.2	189.
$C_8H_6O_4$	Piperonylic acid (s)	166.05	30	803.5	3,362.7		163.
$C_8H_8O_3$	*p*-Methoxybenzoic acid (s)	152.06	34	894.6	3,743.9	901.7	189.
$C_8H_8O_3$	1,6,2-Hydroxytoluic acid (s)[93]	152.06	34	882.8	3,694.5	882.2	199.
$C_8H_8O_3$	1,2,3-Hydroxytoluic acid (s)	152.06	34	878.7	3,677.4	882.2	199.
$C_8H_8O_3$	1,2,5-Hydroxytoluic acid (s)	152.06	34	879.5	3,680.7	882.2	199.
$C_8H_8O_3$	1,2,4-Hydroxytoluic acid (s)	152.06	34	877.8	3,673.6	882.2	199.
$C_{10}H_{10}O_5$	Opianic acid (s)	210.08	40	1,089.7	4,557.1	1,090.5	106; cf. 107.
$C_{10}H_{10}O_6$	Hemipinic acid (s)	226.08	38	1,025.0	4,286.6	1,021.9	107.

[91] As a result of a very exhaustive and painstaking investigation, these authors recommend the use of salicylic acid as a secondary thermochemical standard. Compare Verkade and Coops, Bull. soc. chim., **37**, p. 1536, 1925; Verkade and Coops, J. Chem. Soc., p. 1437, 1926; and particularly Cohen, Verkade, Miyaki, Coops and van der Hoeve, Verslag Akad. Wetenschappen Amsterdam, **35**, p. 48; 1926.

[92] The values of these authors have been corrected to the 15° calorie.

[93] The numbers denote the positions of carboxyl, hydroxyl and methyl groups, respectively.

40. PHENYLATED ALIPHATIC ACIDS

$Q = 26.05 \times N - 3.5a - 6.5b$

$C_8H_8O_2$	Phenylacetic acid (s)	136.06	36	[94] 930.2	3,892.9	934.3	208; cf. 66, 241, 5, 106.
$C_8H_8O_3$	Mandelic acid (s)	152.06	34	890.3	3,725.9	895.2	199; cf. 182.
$C_8H_8O_3$	Phenoxyacetic acid (s)	152.06	34	902.8	3,778.2	911.7	199.
$C_9H_8O_2$	Phenylpropiolic acid (s)	146.05	38	1,021.1	4,270.2	1,016.5	138; cf. 182.
$C_9H_8O_2$	Cinnamic acid (s) (*trans*)	148.06	40	1,040.2	4,357.4	1,048.0	177; cf. 189, 155, [95] 145.
$C_9H_8O_2$	Allocinnamic acid (s) (*cis*) (M. P. 58°).	148.06	40	1,047.0	4,385.9	1,052.0	177; cf. 183, 108.
$C_9H_8O_2$	Atropic acid (s)	148.06	40	1,044.4	4,370.8	1,045.0	183; cf. 145.
$C_9H_8O_3$	*p*-Hydroxycinnamic acid (s) (*trans*) (M. P. 206°).	164.06	38	991.4	4,152.9	999.9	177.
$C_9H_8O_3$	Allo-*p*-hydroxycinnamic acid (s) (*cis*) (M. P. 126 to 127°).	164.06	38	996.5	4,174.3	1,003.4	177.
$C_9H_{10}O_2$	Hydrocinnamic acid (s) (β-phenylpropionic acid).	150.08	42	1,085.0	4,540.7	1,090.6	189.
$C_{10}H_8O_4$	Piperonylacrylic acid (s) (*trans*) (M. P. 238°).	192.06	40	1,067.5	4,471.8		177.
$C_{10}H_8O_4$	Allopiperonylacrylic acid (s) (*cis*) (M. P. 99 to 100°).	192.06	40	1,076.5	4,509.5		177.
$C_{10}H_{10}O_2$	Phenylisocrotonic acid (s)[96] (*cis*).	162.08	46	1,195.4	5,002.8	1,208.3	183.
$C_{10}H_{10}O_2$	α-Methylcinnamic acid (s)	162.08	46	1,198.4	5,020.1	1,204.8	163.
$C_{10}H_{10}O_2$	β-Methylcinnamic acid (s)	162.08	46	1,197.0	5,014.2	1,204.8	163.

[94] It is most peculiar that these authors obtained 1,042.8 kg-cal$_{15}$ for this acid while for naphthalene, which was used in standardizing the bomb, their value is 0.9 per cent higher than the accepted value.

[95] One of these authors showed later (Ber., **35**, p. 2908, 1902), that cinnamic acid upon illumination goes over to a α-truxillic acid. However, upon combustion there was no evidence of any energy difference. See also Ber., **28**, p. 1443; 1895; **46**, p. 267; 1913.

[96] $C_6H_5.CH:CH.CH_2COOH$.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

40. PHENYLATED ALIPHATIC ACIDS—Continued

$Q = 26.05 \times N - 3.5a - 6.5b$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_{10}H_{10}O_2$	Methylcoumaric acid (s) (*trans*) (M. P. 182 to 183°).	170.08	44	1,161.0	4,863.4	1,152.5	177.
$C_{10}H_{10}O_2$	Methylcoumarinic acid (s) (*cis*) (M. P. 91 to 92°).	170.08	44	1,167.2	4,889.4	1,156.0	177.
$C_{10}H_{10}O_3$	*p*-Methoxycinnamic acid (s) (*trans*) [97]	170.08	44	1,163.0	4,871.8	1,172.2	177.
$C_{10}H_{10}O_3$	Allo-*p*-methoxycinnamic acid (s) (*cis*) (M. P. 66°).	170.08	44	1,172.2	4,910.4	1,175.7	177.
$C_{11}H_{10}O_2$	Cinnamylideneacetic acid (s) (M. P. 165°).	174.08	50	[98] 1,310.6	5,480.9	1,322.0	155.
$C_{11}H_{10}O_2$	Allocinnamylideneacetic acid (s) (M. P. 138°).	174.08	50	1,319.4	5,517.7	1,325.5	155.
$C_{11}H_{10}O_4$	Acetylcoumaric acid (s) (*trans*) (M. P. 154 to 155°).	206.08	46	1,207.6	5,053.6	1,217.8	177.
$C_{11}H_{10}O_4$	Acetylcoumarinic acid (s) (*cis*) (M. P. 85°).	206.08	46	1,211.7	5,075.8	1,221.3	177.
$C_{11}H_{10}O_4$	Phenylparaconic acid (s)	206.08	46	1,195.5	5,003.2	1,204.8	183.
$C_{11}H_{12}O_2$	Ethylcoumaric acid (s) (*trans*) (M. P. 133 to 134°).	192.10	50	1,316.5	5,514.8	1,328.8	177.
$C_{11}H_{12}O_2$	Ethylcoumarinic acid (s) (*cis*) (M. P. 101 to 102°).	192.10	50	1,323.0	5,542.0	1,332.0	177.
$C_{12}H_{14}O_3$	Propylcoumaric acid (s) (*trans*) (M. P. 105 to 106°).	206.11	56	1,470.4	6,159.5	1,484.8	177.
$C_{12}H_{14}O_3$	Propylcoumarinic acid (s) (*cis*) (M. P. 83 to 84°).	206.11	56	1,476.3	6,184.2	1,488.3	177.
$C_{11}H_{12}O_3$	β-Benzallevulinic acid (s)	204.10	54	1,413.4	5,915.1	1,419.7	182.
$C_{11}H_{12}O_3$	δ-Benzallevulinic acid (s)	204.10	54	1,410.1	5,901.3	1,419.7	182.
$C_{13}H_{18}O_3$	*n*-Butylcoumaric acid (s) (*trans.*) (M. P. 89 to 90°).	220.13	62	1,630.6	6,830.6	1,641.1	177.
$C_{13}H_{18}O_3$	*n*-Butylcoumarinic acid (s) (*cis*) (M. P. 53 to 54°).	220.13	62	1,637.0	6,857.4	1,644.6	177.
$C_{14}H_{18}O_3$	Isoamylcoumaric acid (s) (*trans.*) (M. P. 79 to 79.5°).	234.14	68	1,789.7	7,497.1	1,797.4	177.
$C_{14}H_{18}O_3$	Isoamylcoumarinic acid (s) (*cis*) (M. P. 80 to 80.5°).	234.14	68	1,791.3	7,503.8	1,800.9	177.
$C_{14}H_{12}O_2$	Diphenylacetic acid (s)	212.10	64	1,651.5	6,911.5	1,654.2	182; cf. 227.
$C_{14}H_{12}O_3$	Benzilic acid (s)	228.10	62	1,618.2	6,772.2	1,612.1	182.
$C_{15}H_{16}O_2$	Dibenzylacetic acid (s)	240.13	76	1,954.3	8,178.8	1,972.8	227.
$C_{17}H_{16}O_3$	β-Tolylmethoxycinnamic acid (s) (stable).	268.13	78	2,035.2	8,525.5	2,047.9	151.
$C_{17}H_{16}O_3$	β-Tolylmethoxycinnamic acid (s) (labile).	268.13	78	2,039.2	8,542.2	2,047.9	151.

[F] M. P. 170° (liq. cryst.); clears at 185°.

[98] The work of these investigators is not quite reliable. Thus, the value of standard naphthalene used in the calibration of the bomb is about 0.9 per cent too high, and yet their value for cinnamic acid is within 0.1 per cent of the best value.

41. POLYBASIC AROMATIC ACIDS

$Q = 26.05 \times N - 3.5a - 6.5b$

$C_8H_6O_4$	Phthalic acid (s)	166.05	30	771.0	3,226.6	774.5	189; cf. 183, 127.
$C_8H_6O_4$	Isophthalic acid (s)	166.05	30	768.3	3,215.3	774.5	189.
$C_8H_6O_4$	Terephthalic acid (s)	166.05	30	770.4	3,224.1	774.5	189.
$C_9H_6O_6$	Trimesic acid (s)	210.05	30	767.0	3,209.9	771.0	189.
$C_9H_8O_4$	Uvitic acid (s)	185.06	36	928.3	3,884.9	927.3	189.
$C_{10}H_6O_8$	Pyromellitic acid (s) [99]	254.05	30	776.8	3,250.9	767.5	189.
$C_{12}H_8O_4$	Naphthalic acid (s) (1,8-Naphthalenedicarboxylic acid).	216.05	48	1,244.1	5,202.8	1,230.4	127.
$C_{12}H_6O_{12}$	Mellitic acid (s) [1]	342.05	30	787.5	3,295.7	760.5	189.

[99] The combustion of these acids was rather unsatisfactory. Consult original paper.

[1] See footnote 99.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

42. PHENYLATED POLYBASIC ALIPHATIC ACIDS

$Q = 26.05 \times N - 3.5a - 6.5b$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_{10}H_8O_4$	Benzalmalonic acid (s)	192.06	40	1,056.0	4,419.4	1,048.5	183.
$C_{10}H_{10}O_4$	Benzylmalonic acid (s)	194.08	42	1,082.5	4,530.3	1,090.6	192.
$C_{10}H_{10}O_4$	Phenylsuccinic acid (s)	194.08	42	1,082.3	4,529.4	1,090.6	234.
$C_{12}H_{10}O_4$	Cinnamylidenemalonic acid (s) (yellow).	218.08	50	[3] 1,319.4	5,517.7	1,322.0	155.
$C_{16}H_{14}O_4$	α-Diphenylsuccinic acid (s) (anhydr.) (easily sol. form).[3]	270.11	70	[4] 1,810.3	7,576.1	1,816.5	182; cf. 145.
$C_{16}H_{14}O_4$	β-Diphenylsuccinic acid (s) (difficultly sol.).	270.11	70	1,806.6	7,560.3	1,816.5	182; cf. 145.
$C_{15}H_{16}O_4$	α-Truxillic acid (s)	296.13	80	2,083.5	8,713.2	2,080.0	155.
$C_{24}H_{20}O_8$	Cinnamylidenemalonic acid [5] (exposed to the action of light).	436.16	------	2,638.6	11,034.6	----------	155.

[2] See footnote 95.

[3] The heat of combustion of the acetone addition product of α-diphenylsuccinic acid (easily soluble form in acetone) is given as 2,237.9 kg-cal$_{15}$.

[4] The authors (234) report the heats of combustion of diphenylsuccinic acid (*racem.*) and diphenylsuccinic acid (*anti*) as 1,807.7 kg-cal$_{15}$ and 1,809.0 kg-cal$_{15}$, respectively.

[5] The structure suggested for this polymer is $C_6H_5.CH.CH.CH:C:(CO_2H)_2$

$$(HO_2C)_2:C:CH.CH.CH.C_6H_5.$$

43. HYDROAROMATIC AND POLYMETHYLENE ACIDS

$Q = 26.05 \times N + 13z + 13aa$

$C_4H_6O_2$	Trimethylenecarboxylic acid (Cyclopropanecarboxylic acid).	86.05	18	479.3 483.7	2,007.8 2,022.8	481.9 ----------	175. 215.
$C_5H_6O_4$	α,α-Trimethylenedicarboxylic acid (s) (1,1-Cyclopropanedicarboxylic acid).	130.05	18	482.9	2,020.9	481.9	187.
$C_5H_6O_4$	α,β-Trimethylenedicarboxylic acid (s) (*cis*-1,2-Cyclopropanedicarboxylic acid).	130.05	18	483.9	2,025.1	481.9	187.
$C_5H_8O_2$	Tetramethylenecarboxylic acid (Cyclobutanecarboxylic acid)	100.06	24	641.0 639.2	2,685.2 2,673.1	638.2 ----------	175. 215.
$C_6H_6O_4$	α,α-Tetramethylenedicarboxylic acid (s) (1,1-Cyclobutanedicarboxylic acid).	144.05	24	642.0	2,686.8	638.2	187.
$C_6H_6O_4$	α,β-Tetramethylenedicarboxylic acid (s) (*cis*-1,2-Cyclobutanedicarboxylic acid).	144.05	24	642.1	2,687.2	638.2	187.
$C_6H_6O_4$	α,γ-Tetramethylenedicarboxylic acid (s).	144.05	24	639.4	2,673.9	638.2	243.
$C_7H_{12}O_2$	Cyclohexanecarboxylic acid (Hexahydrobenzoic acid) (M. P. 28°).	128.10	36	934.0	3,905.9	937.8	215.
$C_7H_{12}O_6$	Hexahydrotetrahydroxybenzoic acid (s) (Quinic acid).	192.10	28	[6] 833.3	3,484.9	755.4	43.
$C_7H_{10}O_2$	Δ_2-Tetrahydrobenzoic acid (s).	126.08	34	885.7	3,710.2	892.2	165.
$C_7H_{10}O_2$	Δ_1-Tetrahydrobenzoic acid (s).	126.08	34	856.7	3,586.2	892.2	167.
$C_7H_{10}O_4$	α,β-Pentamethylenedicarboxylic acid (s) (*trans*-1,2-Cyclopentanedicarboxylic acid).	158.08	30	781.5	3,245.9	775.6	187.
$C_7H_6O_8$	$\alpha,\alpha,\beta,\beta$-Trimethylenetetracarboxylic acid (s) (1,1,2,2-Cyclopropanetetracarboxylic acid).	218.05	18	482.7	2,020.1	481.9	187.

[6] The value for this compound appears to be entirely too large and would certainly bear reinvestigation.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

43. HYDROAROMATIC AND POLYMETHYLENE ACIDS—Continued

$Q = 26.05 \times N + 13z + 13aa$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_6H_8O_4$	$\Delta_{1,4}$-Dihydroterephthalic acid (s).	168.06	32	835.6	3,497.0	846.6	185.
$C_6H_8O_4$	$\Delta_{1,5}$-Dihydroterephthalic acid (s).	168.06	32	842.1	3,524.2	846.6	185.
$C_6H_8O_4$	$\Delta_{2,5}$-Dihydroterephthalic acid (s) (*fum.*).	168.06	32	844.9	3,535.9	846.6	186.
$C_6H_8O_4$	Dihydroterephthalic acid (s).	168.06	32	842.6	3,526.3	846.6	186.
$C_8H_{10}O_4$	Δ_2-Tetrahydroterephthalic acid (s).	170.08	34	881.1	3,687.4	892.2	186.
$C_8H_{10}O_4$	Δ_1-Tetrahydroterephthalic acid (s).	170.08	34	882.3	3,692.4	892.2	185.
$C_9H_{12}O_2$	Cyclohexylideneacetic acid (s).[7]	140.10	40	1,042.0	4,364.9	1,055.0	167.
$C_9H_{12}O_2$	Cyclohexene-1-acetic acid (s).	140.10	40	1,044.8	4,376.7	1,048.5	167.
$C_8H_{12}O_4$	Hexahydroterephthalic acid (s) (*trans*).	172.10	36	929.1	3,888.3	937.8	185.
$C_8H_{12}O_4$	Hexahydroterephthalic acid (s) (*cis*).	172.10	36	928.2	3,884.5	937.8	185.
$C_8H_{12}O_4$	1-2-Cyclohexanedicarboxylic acid (s) (*trans*).	172.10	36	930.4	3,893.7	937.8	79.
$C_7H_4O_7.3H_2O$	Meconic acid (s)	254.08	------	490.08	2,052.5	----------	106.
$C_8H_{14}O_2$	Cycloheptanecarboxylic acid (s).	142.11	42	1,087.9	4,549.6	1,094.1	215.
$C_8H_{14}O_2$	Hexahydro-*m*-toluic acid (s) (3-Methylhexamethylenecarboxylic acid).	142.11	42	1,086.2	4,542.5	1,094.1	215.
$C_8H_{14}O_2$	Cyclooctanecarboxylic acid (*act*).	142.11	42	1,089.2	4,555.0	1,094.1	215.
$C_9H_{14}O_2$	α-Cyclohexene-1-propionic acid.	154.11	46	1,199.6	5,025.1	1,204.8	167.
$C_{10}H_{16}O_2$	Isocampholytic acid (s)	168.13	52	1,363.0	5,700.1	1,367.6	44.
$C_{10}H_{16}O_2$	Campholenic acid (s) (M. P. 50°).	168.13	52	1,365.7	5,711.4	1,367.6	44.
$C_{10}H_{16}O_3$	α-Tanacetoneketocarboxylic acid (s).	184.13	50	1,327.4	5,560.5	1,322.0	175.
$C_{10}H_{16}O_4$	*d*-Camphoric acid (s)	200.13	48	[8] 1,243.8	5,205.3	1,250.4	187; cf. 124, 127, 112.
$C_{10}H_{18}O_2$	Campholic acid (s)	170.14	54	1,412.0	5,904.9	1,406.7	44.
$C_{10}H_{18}O_2$	Hexahydrocumic acid (s)	170.14	54	[9] 1,396.4	5,839.7	1,406.7	243.
$C_{12}H_{12}O_{12}$	Hexahydromellitic acid (s) (*fum*).	348.10	36	923.2	3,863.6	937.8	186.

[7] C_6H_{10} : $CH.COOH$.
[8] Values of (124), (127), and (112) vary between 1,242.5 and 1,254.2 kg-cal$_{15}$.
[9] This value has been corrected according to the method employed by Swietoslawski, J. Amer. Chem. Soc., 42, p. 1093; 1920. The correction factor employed by him appears to be too large, however.

44. ACID ANHYDRIDES

$Q = 26.05 \times N + 10bb$

$C_4H_2O_3$	Maleic anhydride (s)	98.02	12	333.9	1,397.4	339.1	182.
$C_4H_4O_3$	Succinic anhydride (s)	100.03	14	369.4	1,545.9	374.3	182.
				369.6	1,546.8	----------	234; cf. 127.
$C_4H_6O_3$	Acetic anhydride (v)	102.00	16	458.3	1,916.6	----------	223.
	Acetic anhydride (liq.)	----------	------	431.9	1,806.2	426.8	
$C_5H_4O_3$	Itaconic anhydride (s)	112.03	18	481.5	2,015.1	491.9	183.
$C_5H_6O_3$	Glutaric anhydride (s)	114.05	20	528.0	2,209.7	531.0	183.
$C_5H_6O_3$	Monomethylsuccinic anhydride (s).	114.05	20	527.7	2,208.4	531.0	234.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

44. ACID ANHYDRIDES—Continued

$Q = 26.05 \times N + 10bb$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal $_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal $_{15}$ (calculated to the liquid state)	Literature
$C_6H_8O_3$	Dimethylsuccinic anhydride (s) (*unsym.*).	128.06	26	682.6	2,856.7	687.3	234.
$C_6H_8O_3$	Dimethylsuccinic anhydride (*sym.*) (M. P. 87°).	128.06	26	679.3	2,842.9	687.3	234.
$C_6H_8O_3$	Dimethylsuccinic anhydride (M. P. 43°).	128.06	26	681.1	2,850.4	687.3	234.
$C_6H_8O_3$	Monoethylsuccinic anhydride.	128.06	26	684.8	2,865.9	687.3	234.
$C_6H_{10}O_3$	Propionic anhydride	130.08	28	746.6	3,122.3	739.4	118.
$C_7H_{10}O_3$	Trimethylsuccinic anhydride (s).	142.08	32	836.1	3,499.1	843.6	234.
$C_8H_4O_3$	Phthalic anhydride (s)	148.03	30	783.4 780.5	3,278.5 3,266.4	784.5	189, 217; cf. 127.
$C_8H_{10}O_3$	Hexahydrophthalic anhydride (s) (sol.) (*cis*).	154.08	36	932.0	3,900.4	947.8	172.
$C_8H_{12}O_3$	Hexahydrophthalic anhydride (s) (sol.) (*trans.*).			937.8	3,924.7		172.
$C_8H_{12}O_3$	Tetramethylsuccinic anhydride (s).	156.09	38	992.6	4,154.0	999.9	234.
$C_8H_{12}O_3$	Diethylsuccinic anhydride (s) (*unsym.*).	156.09	38	998.3	4,177.9	999.9	234.
$C_8H_{12}O_3$	Diethylsuccinic anhydride (s) (*racem.*) (*sym.*).	156.09	38	995.6	4,166.6	999.9	234.
	Diethylsuccinic anhydride (s) (*racem.*) (*anti*).			997.2	4,173.2		234.
$C_{10}H_8O_3$	Phenylsuccinic anhydride (s)	176.06	42	1,094.1	4,578.8	2,106.6	234.
$C_{10}H_{14}O_3$	Camphoric anhydride (s)	182.11	48	[10] 1,251.8	5,238.8	1,260.4	183; cf. 127, 124.
$C_{10}H_{16}O_3$	Triethylsuccinic anhydride (s).	184.12	50	1,309.5	5,480.3	1,312.5	234.
$C_{12}H_6O_3$	Naphthalic anhydride (s)	198.05	48	[11] 1,257.6	5,259.3	1,240.4	127.
$C_{12}H_{20}O_3$	Tetraethylsuccinic anhydride (s).	212.15	62	1,621.3	6,785.1	1,625.1	234.
$C_{12}H_{22}O_3$	Diethylacetic anhydride (s)	214.18	64	1,669.1	6,980.2	1,677.2	227.
$C_{14}H_{10}O_3$	Benzoic anhydride (s)	226.08	60	1,555.1	6,508.1	1,566.0	205; cf. 27.
$C_{14}H_{26}O_3$	Heptylic anhydride (s)	242.21	76	1,985.5	8,303.4	1,989.8	227.
$C_{16}H_{12}O_3$	Diphenylsuccinic anhydride (*racem.*) (s).	252.10	70	1,815.9	7,599.5	1,826.5	234.
$C_{16}H_{10}O_3$	Diphenylmaleic anhydride (s).	250.08	68	1,768.9	7,402.9	1,774.9	182.
$C_{18}H_{14}O_3$	Cinnamic anhydride (s)	298.11	80	2,091.3	8,745.8	2,107.0	227.
$C_{28}H_{22}O_3$	Diphenylacetic anhydride (s).	406.18	128	3,308.0	13,834.1	3,337.4	227.
$C_{32}H_{30}O_3$	Dibenzylacetic anhydride (s) (glassy).	462.24	152	3,931.4	16,441.1	3,962.6	227.

[10] The mean of several values.

[11] Individual determinations do not agree better than 0.7 per cent; values of (127) are also on the whole 1 per cent higher than those of (183).

VIII. TABLES OF DATA—Continued

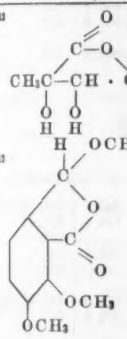
2. CHO COMPOUNDS—Continued

45. LACTONES

$Q = 26.05 \times N + 13$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{18}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_6H_{10}O_5$	Saccharinic acid lactone (s)[12]	162.08	24	656.6	2,747.9	662.2	195.
$C_6H_{10}O_6$	*l*-Gulonolactone (s)	178.08	22	614.7	2,570.7	625.1	68.
$C_6H_{10}O_6$	*l*-Mannolactone (s)	178.08	22	616.3	2,577.4	625.1	68.
$C_6H_{10}O_6$	*d*-Mannolactone (s)	178.08	22	618.7	2,587.4	625.1	68.
$C_7H_{10}O_4$	Terebic acid (s) (γ,γ-Dimethylparaconic acid).	158.08	30	778.3	3,254.9	794.5	145.
$C_7H_{12}O_7$	Glucoheptonic acid lactone (s).	208.10	26	726.3	3,037.4	735.8	68.
$C_8H_6O_2$	Phthalide (s)	134.05	34	884.1	3,699.9	891.7	199; cf. 157.
$C_8H_{14}O_5$	Glucooctonolactone (s)	238.11	30	836.7	3,499.1	843.5	68.
$C_{10}H_{10}O_4$	Meconine (Dimethoxyphthalide).	194.08	42	1,136.7	4,753.7	1,139.1	106; cf. 107.
$C_{11}H_{12}O_5$	Methyl opianate (s)	224.10	46	[13] 1,262.9	5,281.5	1,139.1	106.

[12]



[13]

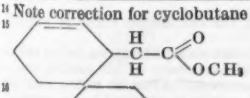
46. METHYL ESTERS OF MONOBASIC ACIDS

$Q = 26.05 \times N + 16.5$

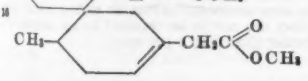
Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{18}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_2H_4O_2$	Methyl formate (v)	60	8	240.2	1,004.5	----------	223; cf. 40.
	Methyl formate (liq.)	60.03	------	233.1	974.8	----------	26.
$C_3H_6O_2$	Methyl acetate (v)	74	14	397.7	1,663.2	----------	223.
	Methyl acetate (liq.)	74.05	------	390.0	1,631.0	381.2	78.
				381.2	1,595.2	----------	172; cf. 65.
$C_4H_8O_2$	Methyl propionate (v)	88	20	552.3	2,309.7	537.5	223.
$C_4H_8O_3$	Methyl lactate	104.06	18	497.2	2,079.3	498.3	75.
$C_5H_{10}O_2$	Methyl butyrate	102	26	692.8	2,897.3	693.8	65.
$C_5H_{10}O_2$	Methyl isobutyrate	102.08	26	694.2	2,904.5	693.8	154.
$C_5H_8O_3$	Methyl acetylacetate	116.06	------	594.0	2,484.1	----------	78.
$C_6H_{10}O_2$	Methyl dimethylacrylate	114.08	30	804.4	3,369.6	810.8	163.
$C_6H_{10}O_2$	Methyl cyclobutanecarboxylate.	114.08	30	[14] 809.1	3,383.7	810.8	215.
$C_9H_{14}O_2$	Methyl cyclohexene-1-acetate.[15]	154.11	46	1,210.1	5,069.1	1,221.3	167.
$C_9H_{14}O_2$	Methyl cyclohexylideneacetate.	154.11	46	1,216.5	5,095.9	1,221.3	167.
$C_{10}H_{16}O_2$	Methyl α-cyclohexene-1-propionate.	168.13	52	1,349.3	5,652.2	----------	167.5.
$C_{10}H_{16}O_2$	Methyl methyl-4-cyclohexylidene-1-acetate.[16]	168.13	52	1,373.9	5,755.3	1,377.6	167.
$C_{10}H_{16}O_2$	Methyl methyl-4-cyclohexene-1-acetate.	168.13	52	1,362.0	5,705.5	1,377.6	167.
$C_{10}H_{16}O_2$	Methyl α-cyclohexylidenepropionate.	168.13	52	1,374.6	5,758.2	1,377.6	167.
$C_{11}H_{18}O_2$	Methyl pinonate	198.14	56	1,477.3	6,188.4	1,481.8	175.

[14] Note correction for cyclobutane ring in formula for polymethylenecarboxylic acids.

[15]



[16]



VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

47. METHYL ESTERS OF MONOBASIC AROMATIC ACIDS

$Q = 26.05 \times N + 16.5 - 3.5a - 6.5b$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_8H_8O_2$	Methyl benzoate	136.06	36	943.5	3,948.6	950.8	205.
$C_8H_8O_3$	Methyl salicylate	152.06	34	898.3	3,759.4	902.2	206.
$C_8H_8O_3$	Methyl *p*-hydroxybenzoate (s).	152.06	34	895.4	3,747.3	902.2	191.
$C_8H_8O_5$	Methyl gallate (s)	184.06	30	801.6	3,354.7	805.0	191.
$C_9H_{10}O_3$	Methyl anisate (s)	166.08	40	1,068.7	4,472.5	1,074.5	191.
$C_{10}H_{10}O_2$	Methyl cinnamate (s)	162.08	46	1,213.0	5,076.4	1,221.3	191.
				1,210.4	5,070.4		163.
$C_{10}H_8O_2$	Methyl phenylpropiolate	160.06	44	1,196.2	5,002.5	1,189.3	138.
$C_{12}H_{10}O_2$	Methyl β-naphthoate (s)	186.08	54	1,401.5	5,865.3	1,406.7	191.
$C_{12}H_{14}O_3$	Methyl ethylcoumarate (*trans*).	206.11	56	1,490.3	6,242.9	1,501.3	177.
$C_{12}H_{14}O_3$	Methyl ethylcoumarinate (*cis*).	206.11	56	1,495.0	6,262.6	1,504.8	177.

48. METHYL ESTERS OF POLYBASIC ALIPHATIC ACIDS

$Q = 26.05 \times N + 16.5dd$

$C_3H_6O_3$	Dimethyl carbonate	90.05	12	340.8	7,290.5	345.7	215; cf. 119.
$C_4H_6O_4$	Dimethyl oxalate (s)	118.05	14	401.9	1,681.9	410.8	191.
				401.0	1,678.2		233.
$C_5H_8O_4$	Dimethyl malonate	132.06	20	552.2	2,309.3	554.1	78.
				554.3	2,319.8		233.
$C_6H_8O_4$	Dimethyl fumarate (s)	144.06	24	664.3	2,780.1	[17] 671.3	191; cf. 145.
$C_6H_8O_4$	Dimethyl maleate (s)	144.06	24	669.2	2,798.6	674.8	145.
$C_6H_{10}O_4$	Dimethyl succinate	146.06	26	708.2	2,963.8	710.4	191.
				707.4	2,960.5		233.
	Dimethyl succinate (s)			703.3	2,943.3		191.
$C_6H_{10}O_6$	Dimethyl racemate (s)	178.08	22	[17a] 617.8	2,583.6		145.
				617.3	2,581.6		10; cf. 180.
$C_6H_{10}O_6$	*d*-Dimethyl tartrate (s)	178.08	22	619.0	2,588.7		145.
				618.3	2,585.8		10 cf; 9.
$C_6H_{10}O_6$	Dimethyl mesotartrate (s)	178.08	22	617.3	2,581.6	632.2	10; cf. 180.
$C_7H_{10}O_4$	Dimethyl trimethylene-α, α-dicarboxylate.	158.08	30	826.9	3,463.9	827.6	175.
$C_7H_{10}O_5$	Dimethyl acetylmalonate	174.08	28	752.8	3,148.2	769.0	78.
$C_7H_{12}O_4$	Dimethyl glutarate	160.09	32	853.2	3,612.5	866.7	233.
$C_8H_{12}O_4$	Dimethyl tetramethylene-α, β-dicarboxylate.	172.10	36	983.5	4,119.9	983.8	175.
$C_8H_{14}O_4$	Dimethyl adipate	174.11	38	1,019.6	4,267.0	1,023.0	233.
$C_9H_{16}O_4$	Dimethyl pimelate	188.12	44	1,176.0	4,921.5	1,179.3	233.
$C_{10}H_{18}O_4$	Dimethyl suberate	202.14	50	1,333.2	5,579.4	1,335.6	233.
$C_{11}H_{20}O_4$	Dimethyl azelate	216.15	56	1,488.3	6,228.5	1,491.9	233.
$C_{12}H_{22}O_4$	Dimethyl sebacate	230.17	62	1,644.7	6,883.1	1,648.2	233.
	Dimethyl sebacate (s)			1,635.8	6,845.8		233.
$C_9H_{14}O_7$	Trimethyl citrate (s)	234.11	36	983.0	4,113.9	993.9	191.
$C_9H_{16}O_4$	Dimethyl pentamethylene-$\alpha\beta$-dicarboxylate.	186.11	42	1,116.6	4,677.4	1,127.2	175.
$C_{10}H_{12}O_4$	Dimethyl Δ-1,4-dihydroterephthalate (s).	196.1	44	1,180.6	4,946.8	1,192.3	185.
$C_{10}H_{14}O_4$	Dimethyl Δ-tetrahydroterephthalate (s).	198.11	46	1,226.2	5,131.7	1,237.8	185.

[17] The heat of fusion of dimethyl fumarate is 8.3, which would bring the calculated value to approximately 663.0 kg-cal.

[17a] The work of (10) is much more accurate than that of (145), and preference should be given to his values. The values of (145) are included here merely to allow one to estimate the accuracy of his results and to use this information as a guide in estimating the accuracy of his measurements when no other measurements are available. His results vary widely. On the whole, they are not to be trusted to an accuracy greater than 0.5 per cent, and in many cases the values are not better than 1 to 2 per cent.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

48. METHYL ESTERS OF POLYBASIC ALIPHATIC ACIDS—Continued

$Q = 26.05 \times N + 16.5dd$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{18}$ (calculated to the liquid state)	Literature
$C_{10}H_{16}O_8$	Tetramethyl ethanetetracarboxylate (s) (*sym.*).	262.11	38	1,045.1	4,373.7	1,056.0	183.
$C_{10}H_{16}O_4$	Dimethyl norpinate (*cis*) (Dimethyl 1,1-dimethylcyclobutane-2,4-dicarboxylate).	200.13	48	1,287.5	5,393.3	1,296.5	175.
$C_{10}H_{16}O_4$	Dimethyl hexahydroterephthalate (*fum*) (s)	200.13	48	1,273.5	5,329.6	1,283.5	185.
$C_{11}H_{14}O_8$	Tetramethyl $\alpha, \alpha, \beta, \beta$-trimethylenetetracarboxylate (s).	274.11	42	1,169.7	4,895.2	1,173.2	187.
$C_{11}H_{16}O_4$	Dimethyl spiroheptanedicarboxylate.	212.13	52	1,407.7	5,896.9	1,400.6	175.
$C_{11}H_{16}O_8$	Tetramethyl methylenedimalonate [15] (s).	276.13	44	1,201.4	5,027.9	1,212.3	187.
$C_{11}H_{18}O_4$	Dimethyl α-tanacetonedicarboxylate.	214.14	54	1,451.4	6,079.9	1,452.7	175.
$C_{11}H_{18}O_4$	Dimethyl pinate	214.14	54	1,440.2	6,032.9	1,452.7	175.

[15] $(CH_3.CO_2)_2.CH.CH_2.CH(CO_2CH_3)_2$.

49. METHYL ESTERS OF POLYBASIC AROMATIC ACIDS

$Q = 26.05 \times N + 16.5dd - 3.5a - 6.5b$

$C_{10}H_{10}O_4$	Dimethyl phthalate	194.08	42	1,119.7	4,685.9	1,120.1	191.
$C_{10}H_{10}O_4$	Dimethyl isophthalate (s)	194.08	42	1,111.1	4,649.9	1,120.1	191.
$C_{10}H_{10}O_4$	Dimethyl terephthalate (s)	194.08	42	1,111.6	4,652.0	1,120.1	191; cf. 185.
$C_{11}H_{12}O_6$	Trimethyl trimesate (s)	252.10	48	1,291.7	5,405.8	1,289.4	191.
$C_{18}H_{16}O_4$	Dimethyl diphenylmaleate (s).	296.13	80	2,111.9	8,838.3	2,120.5	183.
$C_{18}H_{18}O_{12}$	Hexamethyl mellitate (s)	426.13	66	[19] 1,824.3	7,634.7		191.
$C_{20}H_{20}O_4$	Dimethyl β-truxillate (s)	324.16		2,421.6	10,134.4		183.

[19] This value is not quite satisfactory, although it is the mean of a number of determinations.

50. ETHYL ESTERS OF MONOBASIC ALIPHATIC ACIDS

$Q = 26.05 \times N + 16.5$

$C_3H_6O_2$	Ethyl formate (v)	74.0	14	398.4	1,666.1		223.
	Ethyl formate (liq)	74.05		391.7	1,638.1		26; cf. 65.
$C_4H_8O_2$	Ethyl acetate (v)	88.0	20	544.4	2,276.7	537.5	223.
	Ethyl acetate (liq)	88.06		536.9	2,245.3		78.
				539.9	2,257.9		172.
$C_5H_8O_2$	Ethyl propiolate	98.05	22	634.8	2,654.7	635.7	138.
$C_5H_{10}O_2$	Ethyl propionate	102.08	26	690.8	2,891.0	693.8	172.
$C_5H_{10}O_3$	Ethyl lactate	118.08	24	653.3	2,732.1	654.7	75; cf. 118.
$C_6H_{10}O_3$	Ethyl acetoacetate	130.08	28	753.6	3,151.6	755.4	112.
$C_6H_{12}O_2$	Ethyl *n*-butyrate	116.10	32	851.2	3,559.7	850.1	118.
$C_6H_{12}O_2$	Ethyl isobutyrate	116.10	32	845.7	3,536.7	850.1	118.
$C_7H_{12}O_2$	Ethyl tetramethylenecarboxylate.	128.10	36	965.1	8,297.9	967.3	175.
$C_7H_{12}O_2$	Ethyl angelate	128.10	36	964.2	4,035.2	967.8	151.
$C_7H_{12}O_2$	Ethyl tiglate (s)	128.10	36	954.4	3,994.2	967.8	151.
$C_7H_{12}O_2$	Ethyl allylacetate	128.10	36	971.5	4,065.7	967.8	151.
$C_7H_{12}O_3$	Ethyl α-ethoxyacrylate (s)	144.10	34	926.1	3,875.7	934.7	166.
$C_7H_{12}O_3$	Ethyl β-ethoxyacrylate	144.10	34	923.4	3,864.4	934.7	166.
$C_7H_{14}O_2$	Ethyl valerate	130.11	38	1,017.5	4,255.1	1,006.4	65.
$C_8H_{12}O_2$	Ethyl sorbate	140.10	40	[20] 1,012.0	4,239.3		162.
$C_8H_{12}O_4$	Ethyl diacetylacetate	172.10	36	972.1	4,065.3	967.3	78.

[20] This value is apparently too low and would bear reinvestigation.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

50. ETHYL ESTERS OF MONOBASIC ALIPHATIC ACIDS—Continued

$Q = 26.05 \times N + 16.5$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_6H_{14}O_3$	Ethyl α-ethoxycrotonate (s)	158.11	40	1,076.9	4,506.8	1,091.0	166.
$C_8H_{14}O_3$	Ethyl α-ethylacetoacetate	158.11	40	1,070.9	4,481.6	1,068.0	242.
$C_{10}H_{16}O_3$	Ethyl β, δ-dimethylsorbate	168.13	52	[21] 1,351.3	6,078.8	----------	162.
$C_{10}H_{16}O_2$	Ethyl amylpropiolate	168.13	52	1,394.0	5,829.7	1,404.2	138.
$C_{10}H_{16}O_2$	Ethyl (cyclohexene-1)-acetate.	168.13	52	1,360.4	5,698.7	1,377.6	167.
$C_{10}H_{16}O_2$	Ethyl cyclohexylidene acetate.	168.13	52	1,367.0	5,726.4	1,384.1	167.
$C_{11}H_{16}O_2$	Ethyl 1-methylcyclohexene-1-methene-3-carboxylate.	180.13	------	1,477.0	6,187.2	----------	174.
$C_{11}H_{18}O_2$	Ethyl hexylpropiolate	182.14	58	1,550.8	6,485.5	1,560.5	138.
$C_{11}H_{18}O_2$	Ethyl α-(cyclohexene-1)-propionate.	182.14	58	[22] 1,501.5	6,289.8	----------	167.
$C_{11}H_{18}O_3$	Ethyl methyl-1-ethyl-4-cyclopentanone carboxylate.[23]	198.14	------	1,465.8	6,129.9	----------	215.
$C_{12}H_{18}O_2$	Ethyl 1,3-Dimethyl-4-cyclohexene-3-methene-5-carboxylate.	194.14	------	1,631.4	6,833.9	----------	176.

[21] This value appears to be low.
[22] This value appears to be low.
[23] In the article by Swietoslawski (J. Amer. Chem. Soc., 40, p. 1099; 1920) the compound is named "ethyl ester of methylethyl-1,4-cyclopentanecarboxylic acid." However, neither the empirical formula nor the molecular weight corresponds to the above name. The above formula is suggested, for it corresponds to the molecular weight given.

51. ETHYL ESTERS OF MONOBASIC AROMATIC ACIDS

$Q = 26.05 \times N + 16.5 - 3.5a - 6.5b$

$C_9H_{10}O_2$	Ethyl benzoate	150.08	42	1,098.7	4,598.1	1,107.1	205.
$C_9H_{10}O_3$	Ethyl salicylate	166.08	40	1,051.2	4,399.3	1,055.0	206.
$C_9H_{10}O_3$	Ethyl p-hydroxybenzoate (s)	166.08	40	1,042.8	4,364.1	1,055.0	206.
$C_{11}H_{10}O_2$	Ethyl phenylpropiolate	174.08	50	1,338.6	5,598.0	1,345.6	138.
$C_{12}H_{14}O_2$	Ethyl α-methylcinnamate [24]	190.11	58	1,526.8	6,395.8	1,533.9	163.
$C_{12}H_{14}O_2$	Ethyl β-methylcinnamate	190.11	58	1,527.5	6,398.7	1,533.9	163.
$C_{12}H_{14}O_3$	Ethyl methylcoumarinate	206.11	56	1,494.2	6,259.2	1,501.3	177.

[24] See also Ber., 25, p. 90; 1892, for heats of combustion of polymers of ethyl cinnamate.

52. ETHYL ESTERS OF POLYBASIC ALIPHATIC ACIDS

$Q = 26.05 \times N + 16.5dd$

$C_5H_{10}O_3$	Diethyl carbonate	118.08	24	{ 647.9 642.1	2,709.5 2,685.3	---------- ----------	215. 119.
$C_6H_{10}O_4$	Diethyl oxalate	146.08	26	716.0	2,994.3	723.3	119.
$C_7H_{12}O_4$	Diethyl malonate	160.10	32	860.4	3,598.2	866.6	119.
$C_8H_{14}O_4$	Diethyl succinate	174.11	38	1,007.3	4,212.5	1,022.9	119.
$C_8H_{14}O_6$	Diethyl d-tartrate	206.11	34	930.6	3,894.6	931.7	9.
$C_8H_{14}O_6$	Diethyl mesotartrate	206.11	34	931.3	3,896.9	931.7	9.
$C_8H_{10}O_4$	Diethyl acetylenedicarboxylate.	170.08	34	957.6	4,004.7	951.8	138.
$C_{10}H_{18}O_4$	Diethyl dimethylsuccinate (*sym.*).	202.14	50	1,328.9	5,561.4	1,335.5	183.
$C_{10}H_{18}O_4$	Diethyl dimethylsuccinate (*rac.*).	202.14	50	1,322.9	5,536.3	1,335.5	9.
$C_{10}H_{18}O_4$	Diethyl dimethylsuccinate (*meso*) (s).	202.14	50	1,324.1	5,541.4	1,335.5	9.
$C_{12}H_{20}O_7$	Triethyl citrate	276.16	54	1,459.1	6,101.9	1,462.7	118.
$C_{14}H_{20}O_8$	Tetraethyl ethylenetetracarboxylate (s).	316.16	60	1,627.7	6,811.9	1,642.0	183.
$C_{14}H_{22}O_8$	Tetraethyl ethanetetracarboxylate (*sym.*) (s).	318.18	62	1,661.2	6,952.1	1,681.1	
$C_{20}H_{22}O_4$	Diethyl diphenylsuccinate (*rac.*) (s).	326.18	94	2,450.8	10,256.6	2,474.9	166.
$C_{20}H_{22}O_4$	Diethyl diphenylsuccinate (*meso*) (s).	326.18	94	2,449.4	10,250.7	2,474.9	166.

VIII. TABLES OF DATA—Continued

2. CHO COMPOUNDS—Continued

53. ESTERS OF ALIPHATIC ACIDS

(All types)

$Q = 26.05 \times N + 16.5dd$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_4H_6O_2$	Allyl formate (v)	86.0	18	525.8	2,198.9		223.
$C_4H_6O_2$	Vinyl acetate	86.05	18	498.1	2,084.5	498.4	164.
$C_5H_8O_2$	Allyl acetate	100.06	24	655.8	2,742.6	654.7	119.
$C_7H_{14}O_2$	Amyl acetate	130.11	40	[25] 1,042.5	4,359.7	1,058.5	158.
$C_{12}H_{20}O_2$	Propyl hexylpropiolate	196.16	64	1,717.3	7,181.8	1,716.8	138.
$C_{18}H_{36}O_2$	Cetyl acetate (s)	284.2	104	2,728.1	11,417.1	2,725.7	183.
$C_{32}H_{64}O_2$	Cetyl palmitate (s)	480.51	188	4,872.8	20,392.7	4,913.9	181.

[25] The accuracy of the method employed and the value for the compound given are probably not better than 1 per cent.

54. ESTERS OF AROMATIC ACIDS

(All types)

$Q = 26.05 \times N + 16.5$

$C_{10}H_{12}O_2$	Propyl benzoate	164.10	48	1,254.5	5,250.1	1,263.4	205.
$C_{10}H_{12}O_3$	Propyl salicylate	180.10	46	1,205.7	5,045.9	1,214.8	206.
$C_{10}H_{12}O_3$	Propyl *p*-hydroxybenzoate (s).	180.10	46	1,200.6	5,024.5	1,214.8	206.
$C_{11}H_{14}O_2$	Isobutyl benzoate	178.11	54	1,411.4	5,906.7	1,419.7	205.
$C_{11}H_{14}O_3$	Isobutyl salicylate	194.0	52	1,365.5	5,714.6	1,371.1	206.
$C_{12}H_{16}O_2$	Amyl benzoate	192.13	60	1,569.5	6,568.4	1,576.0	205.
$C_{12}H_{14}O_2$	Propyl cinnamate	190.11	58	1,526.0	6,392.4	1,533.9	163.
$C_{48}H_{38}O_{12}$	Mannitol hexabenzoate (s)	806.30	206	5,358.5	22,425.3		206.

55. PHENOL ESTERS

$Q = 26.05 \times N + 16.5 - 3.5a - 6.5b + 3.5m$

$C_{12}H_{14}O_3$	Eugenol acetate (s)	206.11	56	1,497.8	6,268.3	1,504.3	196.
$C_{12}H_{14}O_3$	Isoeugenol acetate (s)	206.11	56	1,488.2	6,228.1	1,501.3	196.
$C_{13}H_{10}O_2$	Phenyl benzoate (s)	198.08	58	1,510.5	6,321.4	1,523.9	183.
$C_{14}H_{12}O_2$	*p*-Cresyl benzoate (s)	212.10	64	1,660.1	6,947.5	1,680.2	205.
$C_{14}H_{12}O_4$	Guaiacol salicylate (s)	244.10	60	1,589.8	6,653.3	1,583.0	192.
$C_{15}H_{14}O_2$	*o*-Xylenyl benzoate (s)	226.11	70	1,814.3	7,592.9	1,829.5	205.
$C_{16}H_{16}O_2$	Pseudocumenyl benzoate (s)	240.13		1,967.8	8,235.2		205.
$C_{17}H_{18}O_2$	{Thymyl benzoate (s)	254.14	82	2,127.6	8,904.0		205.
	{Thymyl benzoate (liq.)			2,131.9	8,922.0	2,142.1	205.
$C_{17}H_{16}O_3$	Eugenol benzoate (s)	268.13	78	2,064.1	8,638.3	2,074.4	196.
$C_{17}H_{16}O_3$	Isoeugenol benzoate (s)	268.13	78	2,054.9	8,599.8	2,071.4	196.
$C_{17}H_{16}O_3$	Allyl-3,4-guaiacol benzoate (s) (Betel benzoate).	268.13	78	2,064.3	8,639.1	2,073.9	196.
$C_{26}H_{18}O_4$	Resorcyl dibenzoate (s)	318.11	86	2,237.0	9,361.9	2,266.0	205.

56. GLYCEROL ESTERS

$C_{13}H_{26}O_6$	Glyceryl tributyrate	302.21		1,941.1	8,117.7		215.
$C_{15}H_{20}O_6$	Glyceryl tricyclobutyrate	296.16		1,844.9	7,715.4		215.
$C_{18}H_{32}O_6$	Glyceryl tricyclovalerate	338.21		2,308.6	9,654.6		215.
$C_{24}H_{20}O_6$	Glyceryl tribenzoate (s)	404.16		2,718.9	11,378.6		206.
$C_{39}H_{74}O_6$	Glyceryl trilaurate (s)	638.59		5,706.3	23,880.9		193; cf. 120.
$C_{45}H_{86}O_6$	Glyceryl trimyristate	722.69		6,650.3	27,831.5		193; cf. 120.
$C_{67}H_{98}O_5$	Glyceryl dibrassidate (s)	732.70		6,953.0	29,098.3		193.
$C_{67}H_{98}O_5$	Glyceryl dierucate (s)	732.70		6,979.0	29,207.1		193.
$C_{69}H_{122}O_6$	Glyceryl tribrassidate (s)	1,053.02		10,235.8	42,836.8		193.
$C_{69}H_{122}O_6$	Glyceryl trierucate (s)	1,053.02		10,264.7	42,957.8		193.

VIII. TABLES OF DATA—Continued

3. N COMPOUNDS

57. ALIPHATIC AMINES (PRIMARY)

$Q = 26.05 \times N + 13ee$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
CH_5N	Methylamine (g)	31.0	9	256.9	1,074.4		223.
				261.4	1,092.3		142.
	Methylamine (liq.)	31.05		256.1	1,071.0	247.4	99.[26]
C_2H_7N	Ethylamine (g)	45.0	15	413.1	1,727.6		223.
	Ethylamine (liq.)	45.07		408.5	1,709.6	403.7	99; cf. 15.
$C_2H_8N_2.H_2O$	Ethylenediamine	78.10	16	452.6	1,894.1	442.8	19.
C_3H_7N	Allylamine (g)	57.0	19	528.1	2,208.6		223.
	Allylamine (liq.)	57.07		524.8	2,196.3	521.0	99.
C_3H_9N	Propylamine (g)	59.0	21	572.3	2,393.4		223.
	Propylamine (liq.)	59.08		558.3	2,336.5	560.1	99.
$C_4H_{11}N$	*n*-Butylamine	73.10	27	710.6	2,973.9	716.4	99.
$C_4H_{11}N$	Isobutylamine	73.10	27	713.6	2,986.4	716.4	99.
$C_4H_{11}N$	*Sec.*-Butylamine	73.10	27	713.0	2,983.9	716.4	99.
$C_4H_{11}N$	*Tert.*-Butylamine	73.10	27	716.0	2,996.5	716.4	99.
$C_5H_{13}N$	Isoamylamine	87.11	33	866.8	3,627.6	872.6	99; cf. 143.[27]
$C_5H_{11}N$	1,1-Aminocyclopropylethane	85.10	31	823.3	3,443.0	833.5	215.
$C_6H_{15}N$	Hexylamine	101.13	39	1,022.2	4,277.9	1,028.9	99.
C_7H_9N	Benzylamine	107.08	37	965.8	4,039.0	973.3	101.
				969.4	4,054.0		147.
$C_7H_{15}N$	1-Methylcyclohexylamine-3	113.13	43	1,118.7	4,678.4	1,133.1	215.
$C_7H_{17}N$	Heptylamine	115.14	45	1,178.9	4,933.7	1,185.3	99.
$C_{10}H_{19}N$	Camphylamine	153.16	59	1,533.1	6,416.0	1,576.9	99.

[26] The author (99) used naphthalene to standardize his bomb calorimeter. However, the value he used for naphthalene was 9,665.0 cal./g. The present best value is 9,617.0 cal./g. His values, therefore, ought to be about 0.5 per cent too high, and they have accordingly been corrected by the proper factor. The data are probably not of a high degree of accuracy.

[27] See footnote 28.

58. ALIPHATIC AMINES (SECONDARY)

$Q = 26.05 \times N + 19.5$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
C_2H_7N	Dimethylamine (g)	45.0	15	418.2	1,749.4		223.
				426.0	1,782.8		142.
	Dimethylamine (liq)	45.07		416.7	1,743.9	410.2	99.
$C_4H_{11}N$	Diethylamine (g)	73.0	27	730.6	3,057.6		223.
	Diethylamine (liq)	73.1		722.8	3,024.9	722.9	99.
				[28] 716.9	3,000.2		143.
$C_8H_{19}N$	Diisobutylamine	129.16	51	1,348.4	5,643.1	1,358.1	99.
$C_9H_{13}N$	Benzylethylamine	135.11	49	1,289.6	5,397.1	1,292.5	99.
$C_{10}H_{23}N$	Diisoamylamine	157.19	63	1,660.4	6,948.8	1,660.5	99.
$C_{14}H_{15}N$	Dibenzylamine (s)	197.13	71	1,853.0	7,754.8	1,869.0	99.

[28] Little significance should be attached to values of (143) for the redetermination of the heats of combustion of the three amines by the same author (142) some 25 years later showed enormous variations from the values obtained previously. The values by (142) are, on the whole, too low.

59. ALIPHATIC AMINES (TERTIARY)

$Q = 26.05 \times N + 26$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
C_3H_9N	Trimethylamine (g)	59.0	21	579.5	2,423.5		223.
				592.5	2,479.6		142; cf. 15.
	Trimethylamine (liq)	59.08		578.6	2,421.4	573.1	99.
$C_6H_{15}N$	Triethylamine	101.13	39	[29] 1,036.8	4,339.0	1,042.0	99; cf. 143.
$C_{12}H_{27}N$	Triisobutylamine	185.22	75	1,973.6	8,259.5	1,979.8	99.
$C_{15}H_{33}N$	Triisoamylamine	227.37	93	2,459.3	10,292.2	2,448.9	99.
$C_{21}H_{21}N$	Tribenzylamine (s)	287.17	105	2,762.1	11,559.4	2,761.2	99.

[29] See footnote 28.

VIII. TABLES OF DATA—Continued

3. N COMPOUNDS—Continued

60. AROMATIC AMINES (PRIMARY)

$Q = 26.05 \times N + 6.5 - 3.5hh - 3.5a - 6.5b$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
C_6H_7N	Aniline	93.07	31	812.7	3,401.2	810.5	182.
				811.7	3,396.9	----------	99.
				816.7	3,417.9	----------	211; cf. 184, 147.
C_6H_7NO	*p*-Aminophenol (s)	109.07	29	760.0	3,180.6	765.5	97.
$C_6H_8N_2$	*p*-Phenylenediamine (s)	108.08	32	843.4	3,529.6	839.6	24.
C_7H_9N	*o*-Toluidine	107.08	37	964.3	4,032.7	963.3	147.
C_7H_9N	*m*-Toluidine	107.08	37	965.3	4,036.9	963.3	147.
C_7H_9N	*p*-Toluidine (s)	107.08	37	958.4	4,008.0	963.3	147.
C_7H_9NO	*p*-Anisidine (s)	123.08	35	924.0	3,866.9	934.2	99.
$C_8H_{11}N$	1-Amino-2,4-xylene	121.10	43	1,108.0	4,637.0	1,116.2	99.
$C_9H_{13}N$	Pseudocumidine (s)	135.11	49	1,265.9	5,297.8	1,268.9	99.
$C_{10}H_9N$	α-Naphthylamine (s)	143.08	49	1,263.5	5,287.8	1,266.4	99.
$C_{10}H_9N$	β-Naphthylamine (s)	143.08	49	1,261.0	5,298.2	1,266.4	99.
$C_{12}H_{12}N_2$	Benzidine (s)	184.12	60	1,556.0	6,511.9	1,562.5	100.
				1,560.9	6,532.4	----------	147.
$C_{12}H_{12}N_2$	*o,p*-Diaminodiphenyl	184.12	60	1,561.8	6,536.1	1,562.5	147.
$C_{19}H_{19}N_3O$	Triaminotriphenylcarbinol (s).[30]	305.18	------	2,483.5	10,386.0	----------	179.

[30] This article also contains the heats of combustion of rosaniline hydrochloride and the hexamethylrosaniline hydrochloride.

61. AROMATIC AMINES (SECONDARY)

$Q = 26.05 \times N + 13 - 3.5hh$

C_7H_9N	Methylaniline	107.08	37	973.5	4,071.2	973.3	147; cf. 72.
$C_8H_{11}N$	Ethylaniline	121.10	43	1,121.5	4,693.5	1,129.6	99.
$C_{12}H_{11}N$	Diphenylamine (s)	169.10	59	1,536.2	6,428.9	1,542.9	182.
				1,530.2	6,403.9	----------	99.
$C_{18}H_{13}N$	Phenyl-α-naphthylamine (s)	219.11	77	2,003.8	8,382.6	1,998.8	99.
$C_{18}H_{13}N$	Phenyl-β-naphthylamine (s)	219.11	77	1,998.0	8,361.6	1,998.8	99.

62. AROMATIC AMINES (TERTIARY)

$Q = 26.05 \times N + 19.5 - 3.5hh$

$C_8H_{11}N$	Dimethylaniline	121.10	43	1,142.7	4,782.4	1,136.1	182.
$C_{10}H_{15}N$	Diethylaniline	149.13	55	1,451.6	6,074.9	1,448.7	182.
$C_{18}H_{15}N$	Triphenylamine (s)	245.13	87	2,267.8	9,490.7	2,275.3	182.

63. AMINO ACIDS[31] (ALIPHATIC)

$C_2H_5NO_2$	Glycine (s)	75.05	9	234.5	981.4	----------	194.
				233.4	977.7	----------	241.
$C_3H_7NO_2$	Sarcosine (s) (N-methylglycine).	89.07	15	401.1	1,678.6	----------	195.
$C_3H_7NO_2$	Alanine (s) (α-Aminopropionic acid).	89.07	15	387.7	1,622.5	----------	94.
				389.4	1,631.2	----------	66; cf. 23, 64.
$C_3H_7NO_2$	*d-l*-Alanine (s)	89.07	15	387.5	1,623.2	----------	241.
$C_3H_7NO_2$	*d*-Alanine (s)	89.07	15	387.5	1,623.2	----------	241.
$C_3H_7NO_3$	Isoserine (s)	105.07	13	343.7	1,439.8	----------	241; cf. 66.

[31] The general expression $Q = 26.05 \times N + a$ covers this class of compounds adequately. However, since no heat of fusion is available for this class, it is impossible to estimate the value of "a". It is probably 6.5.

VIII. TABLES OF DATA—Continued

3. N COMPOUNDS—Continued

63. AMINO ACIDS (ALIPHATIC)—Continued

Formula	Name	Molecular weight	Number of electrons (*N*)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_4H_7NO_4$	Diglycolamidic acid (s)	133.07		396.1	1,657.7		198.
$C_4H_7NO_4$	Aspartic acid (s)	133.07		384.9	1,610.8		183; cf. 23.
$C_4H_7NO_4$	*l*-Aspartic acid (s)	133.07		385.6 [33] 383.1	1,615.3 1,601.7		66. 64.
$C_4H_8N_2O_3$	Asparagine (s)	132.08		463.3	1,938.9		194.
$C_4H_8N_2O_3H_2O$	Asparagine (cryst)	150.10		459.7	1,922.0		64.
$C_4H_8N_2O_3$	Glycylglycine (s)	132.08		470.7	1,971.8		66.
$C_5H_8N_2O_5$	Glycylglycinecarboxylic acid (s).	176.08		471.3	1,974.3		241; cf. 66.
$C_5H_{11}NO_2$	*dl*-α-Aminoisovaleric acid (s) (Valine).	117.10		700.8	2,935.7		241.
$C_5H_9NO_4$	Glutamic acid (s) (act.)	147.08		542.4	2,272.1		66; cf. 64.
$C_6H_9NO_6$	Triglycolamidic acid (s)	191.0		559.6	2,341.9		198.
$C_6H_{10}N_2O_2$	Alanine anhydride (s)	142.10		786.4	3,294.2		66.
$C_6H_{10}N_2O_2$	*d*-Alanine anhydride (s)	142.10		786.0	3,292.6		66.
$C_6H_{11}N_3O_4$	Diglycylglycine (s)	189.12		709.8	2,973.4		241.
$C_8H_{12}N_2O_3$	Glycylglycine ethyl ester (s)	160.12		803.2	3,364.6		66.
$C_6H_{13}NO_2$	Leucine (s) (α-aminoisocaproic acid).	131.11		855.6	3,580.7		194; cf. 66, 23.
$C_7H_{13}NO_3$	Formyl-*d*, *l*-leucine (s)	159.11		917.4	3,842.9		241.
$C_8H_{16}N_2O_3$	*d*-*l*-Leucylglycine (s)	188.15		1,095.3	4,588.2		241.
$C_8H_{14}N_4O_5$	Triglycylglycine (s)	246.15		946.6	3,965.3		241.
$C_9H_{16}N_2O_5$	α-Carbethoxyglycylglycine ethyl ester (s).	232.15		1,120.4	4,693.4		66.
$C_9H_{16}N_2O_5$	β-Carbethoxyglycylglycine ethyl ester (s).	232.15		1,091.9	4,573.9		66.
$C_{10}H_{19}N_3O_4$	Leucylglycylglycine (s)	245.18		1,333.1	5,584.4		66.
$C_{12}H_{22}N_2O_2$	Leucineimide (s) (3,6-diisobutyl-2,5-diacipiperazine).	226.20		1,723.8	7,220.9		66.

[33] See footnote 74b.

64. AMINO ACIDS

(Containing a phenyl radical)

$C_8H_9NO_2$	Phenylglycine (s)	151.08		955.1	4,000.9		66.
$C_8H_9NO_2$	Anilidoacetic acid (s)	151.08		965.2	4,043.2		66.
$C_9H_{11}NO_2$	Phenylalanine (s)	165.10		1,111.3	4,655.2		66.
$C_9H_{11}NO_3$	Tyrosine (s)	181.10		1,070.2	4,474.5		64; cf. 23.

65. AMIDES (ALIPHATIC)

$Q = 26.05 \times N$

CH_3NO	Formamide	45.03	5	134.9	564.6		209.
CH_4N_2O	Urea (s)	60.05	6	151.6	633.8	156.3	64; cf. 194, 42, 92.
$C_2H_3NO_3$	Oxamic acid (s)	89.03	5	128.6 132.6	537.8 554.9	130.2	130.[33] 184.
$C_2H_4N_2O_2$	Oxamide (s)	88.05	8	203.2	850.4	208.4	184.
$C_2H_4N_2O_2$	Formylurea	88.05		207.0	865.7		130.
C_2H_5NO	Acetamide (s)	59.05	11	282.6	1,182.7	282.5	209.
$C_3H_4N_2O_4$	Oxaluric acid (s)	132.05	8	207.5	868.4	208.0	130.
$C_3H_5NO_3$	Methyl oxamate (s)	103.05	11	305.4	1,278.1	303.0	184.
$C_3H_6N_2O_2$	Malonamide (s)	102.07	14	358.8	1,501.6	364.7	184.
$C_3H_6N_2O_2$	Acetylurea (s)	102.07	14	360.9	1,510.4	364.7	130.
$C_3H_6N_2O_3$	Hydantoic acid (s)	118.07	12	308.6	1,291.5	312.6	130.
C_3H_7NO	Propionamide (s)	105.07	17	439.9	1,840.9	442.8	209.
$C_3H_7NO_2$	Urethane (s)	89.07	15	397.2	1,662.3	402.7	184.
$C_3H_8N_2O$	Ethylurea (s)	88.08	18	472.0	1,975.3	475.4	130.

[33] The author (130.5) gives the heat of combustion of guanidine nitrate, $CH_6N_4O_3$.

VIII. TABLES OF DATA—Continued

3. N COMPOUNDS—Continued

65. AMIDES (ALIPHATIC)—Continued

$Q = 26.05 \times N$

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_3H_7NO_3$	Ethyl oxamate (s)	117.07	17	457.3	1,913.8	459.3	184.
$C_4H_7N_3O$	Creatinine (s)	113.08		563.4	2,355.6		64.
$C_4H_8N_2O_2$	Succinamide (s)	116.08	20	509.2	2,131.0	521.0	184.
$C_4H_8N_2O_4$	*d*-Tartramide	148.08	16	427.0	1,786.9	429.8	54.
$C_4H_8N_2O_4$	Mesotartramide	148.08	16	426.6	1,785.3	429.8	54.
C_4H_9NO	*n*-Butyramide (s)	87.08	23	596.0	2,494.3	599.2	209.
C_4H_9NO	Isobutyramide (s)	87.08	23	595.9	2,493.8	599.2	209.
$C_4H_9N_3O_2$	Creatine (anhydr.) (s)	131.10		559.8	2,342.8		194.
				555.4	2,322.1		64.
$C_4H_9N_3O_2.H_2O$	Creatine (cryst)	149.12		553.1	2,314.7		194.
$C_5H_{10}N_2O_2$	Dimethylmalonamide (*sym.*) (s).	130.1	26	685.8	2,870.1	677.3	184.
$C_5H_{11}NO$	Isovaleramide (s)	101.10	29	751.5	3,145.0	755.5	209.
$C_7H_{14}N_2O_2$	Diethylmalonamide (s)	158.12	38	994.8	4,163.2	989.9	184.
$C_6H_{13}NO$	Amylpropiolamide (s)	139.11	43	1,150.4	4,810.9	1,153.2	138.
$C_8H_{16}N_2O_4$	*d*-Tartaricdiethylamide	204.14	40	1,064.1	4,453.3	1,068.0	54.
$C_8H_{16}N_2O_4$	*dl*-Tartaricdiethylamide	204.14	40	1,064.3	4,454.1	1,068.0	54.
$C_8H_{16}N_2O_4$	Mesotartaricdiethylamide	204.14	40	1,065.3	4,458.3	1,068.0	54.
$C_9H_{15}NO$	Hexylpropiolamide (s)	153.13	49	1,308.0	5,470.1	1,309.5	138.

66. ACID AMIDES (AROMATIC)

$Q = 26.05 \times N - 3.5hh$

C_7H_7NO	Benzamide (s)	121.07	33	847.6	3,547.2	856.1	209.
C_7H_7NO	Formanilide (s)	121.07	33	861.0	3,603.3		209.
$C_7H_8N_2O$	Monophenylurea (s)	136.08	34	879.6	3,681.1	882.2	184.
C_8H_9NO	Acetanilide (s)	135.08	39	1,010.4	4,228.5	1,012.4	209.
C_7H_7NO	Phenylpropiolamide (s)	145.06	41	1,095.6	4,581.8	1,094.7	138.
$C_9H_9NO_3$	Hippuric acid (s) (Benzoylglycine).	179.08	39	1,012.4	4,236.9	1,018.9	208; cf. 64, 23.
$C_9H_{11}NO$	Propionanilide (s)	149.10	45	1,167.6	4,886.4	1,168.7	209.
$C_9H_{11}NO_3$	Benzoylalanine (s)	193.10	45	1,168.1	4,888.5	1,175.2	208.
$C_9H_{11}NO_3$	Benzoylsarcosine (s)	193.10	45	1,179.8	4,937.5	1,175.2	208.
$C_9H_{11}NO_3$	*o*-Toluylglycine (s) [34]	193.10	45	1,167.7	4,886.8	1,171.7	208.
$C_9H_{11}NO_3$	*m*-Toluylglycine (s)	193.10	45	1,167.0	4,883.9	1,171.7	208.
$C_9H_{11}NO_3$	*p*-Toluylglycine (s)	193.10	45	1,167.5	4,885.9	1,171.7	208.
$C_9H_{11}NO_3$	Phenaceturic acid (s)	193.10	45	1,164.9	4,875.1	1,175.7	208.
$C_9H_{11}NO_4$	*p*-Anisylglycine (s) [35]	209.10	43	1,135.2	4,750.8	1,139.6	208.
$C_{10}H_{13}NO_2$	Phenacetin (s)	179.11	49	1,285.2	5,378.6	1,289.4	160.
$C_{11}H_{13}NO_3$	*o*-Toluylalanine (s)	207.11	51	1,321.7	5,531.3	1,328.0	208.
$C_{11}H_{13}NO_3$	*p*-Toluylalanine (s)	207.11	51	1,319.5	5,522.1	1,328.0	208.
$C_{13}H_{11}NO$	Benzanilide (s)	197.10	61	1,575.5	6,593.5	1,582.1	209.
$C_{13}H_{12}N_2O$	Diphenylurea (s) (*sym.*)	212.12	62	1,612.1	6,746.6	1,608.1	184.
$C_{13}H_{12}N_2O$	Diphenylurea (s) (*unsym.*)	212.12	62	1,614.5	6,756.7	1,608.1	184.
$C_{18}H_{16}N_2O_2$	Succinanilide (s) (*sym.*)	268.15	76	1,970.4	8,246.1	1,972.8	184.
$C_{16}H_{11}NO_2$	Benzalhippuric acid lactone [36]	249.10		1,852.1	7,758.5		66.
$C_{16}H_{13}NO_3$	Benzalhippuric acid (s) (α-Benzoylaminocinnamic acid).[37]	267.11	71	1,848.4	7,742.9	1,852.5	66.
$C_{16}H_{15}NO_3$	Benzoylphenylalanine (s)	269.13	73	1,890.1	7,917.6	1,894.0	66.

[34] $CH_3.C_6H_4.CONH.CH_2.COOH$.
[35] $H_3CO.C_6H_4.CO.NH.CH_2CO_2H$.
[36] $C_6H_5CO.N{-}C{=}CH.C_6H_5$ (with CO below the ring).
[37] $C_6H_5CH : C(CO_2H).HN.OC.C_6H_5$.

VIII. TABLES OF DATA—Continued

3. N COMPOUNDS—Continued

67. CYCLIC UREIDES, HYDANTOINS, PYRIMIDINES, PURINES

Formula	Name	Molecular weight	Number of electrons (*N*)	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_3H_2N_2O_3$	Parabanic acid (s) l(Oxayl-urea).	114.04	.....	212.4	888.9	.....	130.
$C_3H_4N_2O_2$	Hydantoin (s)	100.05	.....	311.7	1,304.5	.....	130.
$C_4H_2N_2O_4.H_2O$	Alloxan (s)	160.05	.....	276.3	1,156.3	.....	130.
$C_4H_4N_2O_3$	Barbituric acid (s)	128.05	.....	358.7	1,501.2	.....	66; cf. 130.
$C_4H_5N_3O_3$	Aminobarbituric acid (s)	143.07	.....	379.1	1,586.5	.....	130.
$C_4H_6N_4O_3$	Allantoin (s) [38]	158.09	.....	413.5	1,730.5	.....	130.
				408.1	1,706.3	.....	64.
$C_5H_4N_4O$	Hypoxanthine (s) (6-Oxypurine).	136.06	.....	821.0	3,435.9	.....	19.
$C_5H_4N_4O$	8-Oxypurine (s)	136.06	.....	591.8	2,476.7	.....	19.
$C_5H_4N_4O_2$	Xanthine (s) (2,6-Dioxypurine).	152.07	.....	514.6	2,153.6	.....	24.
$C_5H_4N_4O_3$	Uric acid (s) [39]	168.07	.....	460.2	1,925.9	.....	194; cf. 130, 64.
$C_5H_5N_5O$	Guanine (s)	151.01	.....	586.4	2,454.1	.....	194.
$C_5H_6N_2O_2$	4-Methyluracil (s)	126.07	.....	566.1	2,371.6	.....	241; cf. 66.
$C_5H_6N_2O_2$	5-Methyluracil (s) (Natural "thymus").	126.07	.....	564.8	2,366.1	.....	66.
$C_5H_8N_2O_3$	Dimethylparabanic acid (s)	142.07	.....	538.3	2,252.8	.....	130.
$C_5H_6N_4O_4$	Pseudouric acid (s)	186.10	.....	454.2	1,900.8	.....	130.
$C_5H_6N_2O_2$	4-Methylhydrouracil (s)	128.08	.....	618.2	2,589.8	.....	66.
$C_6H_6N_4$	7-Methylpurine (s)	134.08	.....	821.0	3,435.9	.....	19.
$C_6H_6N_4O$	7-Methylhypoxanthine (s)	150.08	.....	759.9	3,180.2	.....	19.
$C_7H_8N_4O_2$	Theobromine (s) (3,7-Dimethyl-2,6-dihydroxypurine).	180.11	.....	845.3	3,537.6	.....	130.
$C_5H_6N_4O_3.2H_2O$	Alloxanthine (s)	322.12	.....	583.9	2,443.6	.....	130.
$C_5H_8N_2O_6$	Murexide (s)	284.12	.....	735.9	3,079.7	.....	130.
$C_8H_{10}N_4O_2$	Caffeine (s) (1,3,7-Trimethylxanthine).	194.12	.....	1,014.2	4,244.4	.....	194.
$C_8H_{12}N_2O_3$	Veronal (s)	184.12	.....	983.1	4,113.3	.....	66.
$C_{10}H_8N_2O_2$	4-Phenyluracil (s)	188.08	.....	1,131.0	4,737.8	.....	66.
$C_{12}H_{14}N_4O_6$	Desoxyamalic acid (s)	310.14	.....	1,322.1	5,533.0	.....	130.
$C_{12}H_{14}N_4O_8$	Tetramethylalloxanthine (s) (Amalic acid).	342.15	.....	1,239.3	5,186.5	.....	130.

[38] The author (130) gives the heat of combustion of methylallantoin, $C_5H_8N_4O_3$. Note, however, that the analysis for nitrogen shows a wide divergence from the calculated value. The values of (130) are open to serious objections in that he used camphor to aid in the combustion of the substance. No great reliance should be attached to any of his values.

[39] The author (130) gives also the heat of combustion of ammonium urate, $C_5H_7N_5O_3$.

68. RING NITROGEN COMPOUNDS

C_4H_5N	Pyrrole	67.05	.....	567.7	2,375.8	.....	24.
$C_4H_6N_2O_2$	Diketopiperazine (s) (Glycine anhydride).	114.07	.....	474.6	1,988.1	.....	241; cf. 66.
C_5H_5N	Pyridine	79.05	.....	658.5	2,755.8	.....	53.
				664.8	2,782.2	.....	57.
$C_5H_{11}N$	Piperidine	85.10	.....	826.6	3,459.3	.....	57.
$C_6H_{12}N_4$	Hexamethylenetetramine (s).	140.14	.....	1,006.7	4,212.0	.....	55.
C_6H_7N	α-Picoline	93.07	.....	815.2	3,411.6	.....	53.
C_6H_7N	β-Picoline	93.07	.....	812.2	3,399.1	.....	53.
C_6H_7N	γ-Picoline	93.07	.....	815.8	3,414.1	.....	53.
C_7H_9N	Lutidine [40] (Dimethylpyridine).	107.08	.....	968.0	4,051.1	.....	53.
$C_8H_5NO_2$	Isatin (s) [41]	147.05	.....	867.8	3,631.7	.....	1.
C_8H_7N	Indole (s)	117.07	.....	1,022.2	4,277.9	.....	24.
$C_8H_7NO_2$	Dioxindol (s)	149.07	.....	915.7	3,832.2	.....	1.
$C_9H_{11}N$	Tetrahydroquinoline	135.11	.....	1,228.7	5,142.1	.....	57.

[40] The exact isomer not designated in article.

[41] The author (1) gives also the heat of combustion of isatide, $C_{16}H_{12}N_2O_4$, obtained by reducing isatin with zinc dust in acid solution, as 1,777.8 kg-cal$_{15}$ per mole.

VIII. TABLES OF DATA—Continued

3. N COMPOUNDS—Continued

68. RING NITROGEN COMPOUNDS—Continued

Formula	Name	Molecular weight	Number of electrons (N)	Kg-cals (experimental)	Kilojoules (K. J.)	Kg-cals (calculated to the liquid state)	Literature
C_9H_9N	Skatole (3-Methylindole)	131.08	------	1,170.5	4,898.5	----------	24.
C_9H_9N	α-Methylindole	131.08	------	1,168.7	4,891.0	----------	24.
C_9H_7N	Quinoline	129.06	------	1,123.5	4,701.9	----------	57.
$C_{10}H_9N$	Phenylpyrrole (s)	143.08	------	1,283.5	5,371.5	----------	183.
$C_{10}H_9N$	Quinaldine (α-Methylquinoline).	143.08	------	1,287.7	5,389.0	----------	57.
$C_{10}H_9NO_4$	Opianic acid oxime anhydride (s).	207.08	------	1,151.4	4,818.6	----------	183; cf. 161.
$C_{10}H_{13}N$	Tetrahydroquinaldine	147.11	------	1,382.1	5,784.1	----------	57.
$C_{12}H_9N$	Carbazole (s)	167.08	------	1,475.0	6,172.9	----------	24.
$C_{16}H_{10}N_2O_2$	Indigo (s)	262.10	------	1,815.0	7,595.8	----------	1.
$C_{20}H_{27}NO_{11}$	Amygdalin (s)	457.2	------	2,348.4	9,828.0	----------	19.

69. RING NITROGEN COMPOUNDS, IMIDES

$Q = 26.05 \times N - 3.5hh$

$C_4H_5NO_2$	Succinimide (s)	99.05	17	437.9	1,832.6	442.8	184; cf. 27.
$C_5H_7NO_4$	*dl*-N-Methyltartrimide (s)	145.06	19	516.5	2,161.6	514.4	231.
$C_6H_9NO_4$	*d*-N-Ethyltartrimide (s)	159.08	25	671.1	2,808.6	670.7	231.
$C_6H_9NO_4$	*dl*-N-Ethyltartrimide (s)	159.08	25	671.2	2,809.0	670.7	231.
$C_6H_9NO_4$	N-Ethylmesotartrimide (s)	159.08	25	672.7	2,811.9	670.7	231.
$C_8H_5NO_2$	Phthalimide (s)	147.05	33	849.5	3,555.2	852.6	184.
$C_{10}H_9NO_4$	Hemipinimide (s)	207.08	------	1,099.0	4,599.3	----------	108; cf. 161.
$C_{10}H_9NO_4$	*d*-N-Phenyltartrimide	207.08	41	1,085.7	4,543.7	1,077.6	231.
$C_{10}H_9NO_4$	*dl*-N-Phenyltartrimide	207.08	41	1,085.9	4,544.5	1,077.6	231.
$C_{11}H_{11}NO_4$	*d*-N-Benzyltartrimide (s)	221.10	47	1,237.8	5,180.2	1,240.3	231.
$C_{11}H_{11}NO_4$	*dl*-N-Benzyltartrimide (s)	221.10	47	1,237.7	5,179.8	1,240.3	231.
$C_{11}H_{11}NO_4$	N-Benzylmesotartrimide (s)	221.10	47	1,240.7	5,192.3	1,240.3	231.

70. ALKALOIDS

(Pyridine, Piperidine, Quinoline, and Isoquinoline)

$C_8H_{17}N$	Coniine	127.14	------	1,275.5	5,334.1	----------	19.
$C_{10}H_{14}N_2$	Nicotine	162.13	------	1,427.7	5,974.9	----------	24.
$C_{17}H_{19}NO_3.H_2O$	Morphine (s)	303.18	------	2,146.3	8,975.8	----------	106.
$C_{18}H_{21}NO_3.H_2O$	Codeine (s)	317.20	------	2,327.6	9,734.0	----------	106.
$C_{19}H_{21}NO_3$	Thebaine (s)	311.18	------	2,441.3	10,209.5	----------	106.
$C_{20}H_{21}NO_4$	Papaverine (s)	339.18	------	2,478.1	10,363.4	----------	106.
$C_{21}H_{22}N_2O_2$	Strychnine (s)	334.20	------	2,685.7	11,239.7	----------	28.
$C_{22}H_{23}NO_7$	Narcotine (s)	413.20	------	2,644.5	11,059.3	----------	106.
$C_{23}H_{26}N_2O_4$	Brucine (s)	394.23	------	2,933.0	12,274.6	----------	28.
$C_{22}H_{27}NO_8.2H_2O$	Narceine (s)	481.27	------	2,802.9	11,721.7	----------	106.

71. ALIPHATIC NITRILES

$Q = 26.05 \times N + 16.5$

C_2N_2	Cyanogen (g)	52.0	8	258.3	1,080.2	----------	223.
				262.1	1,096.9	----------	10.
C_2H_3N	Acetonitrile (v)	41.0	------	310.4	1,298.1	----------	223.
	Acetonitrile (liq)	41.03	11	302.4	1,265.5	----------	102.
C_2H_3NO	Glycollic nitrile	57.03	11	256.7	1,074.3	257.4	24.
$C_3H_2N_2$	Malononitrile (s)	84.05	14	394.8	1,652.2	397.7	41.
$C_3H_3NO_2$	Cyanoacetic acid (s)	85.03	11	298.8	1,250.5	303.0	78.
$C_3H_4N_2O$	Cyanoacetamide (s)	84.05	14	376.3	1,574.8	381.2	78.
C_3H_5N	Propionitrile	55.05	17	456.4	1,910.0	459.3	102.
C_4H_5NO	Ethylidene lactonitrile (aldehyde cyanhydrin).	71.05	15	421.1	1,762.3	420.2	24.

VIII. TABLES OF DATA—Continued

3. N COMPOUNDS—Continued

71. ALIPHATIC NITRILES—Continued

$Q = 26.05 \times N + 16.5$

Formula	Name	Molecular weight	Number of electrons	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
C_4N_2	Carbon subnitride (s) (acetylenedicarboxylic acid nitrile).	76.0	16	[42] 514.8	2,152.9	482.9	139.
$C_4H_4N_2$	Succinic acid nitrile	80.04	20	545.7	2,283.7	554.0	41.
C_4H_5N	Allyl cyanide	67.05	21	574.9	2,406.0	576.6	51.
C_4H_5N	Trimethylene nitrile	67.05	21	581.5	2,433.6	576.6	51.
C_4H_5N	Crotononitrile	67.05	21	571.9	2,393.4	576.6	51.
C_4H_5N	Isocrotononitrile	67.05	21	573.8	2,401.4	576.6	51.
$C_4H_5NO_2$	Methyl cyanoacetate	99.05	17	471.6	1,973.7	475.8	78.
$C_4H_5N_3$	Diglycolamidic nitrile (di-(cyanomethyl)amine).[43]	95.07	.....	590.6	2,471.7	.....	198.
C_4H_7N	*n*-Butyronitrile	69.07	23	613.3	2,566.7	615.6	102.
$C_5H_6N_2$	Glutaric nitrile (s)	94.07	26	699.6	2,927.8	710.3	41.
$C_5H_7NO_2$	Ethyl cyanoacetate	113.07	23	630.0	2,636.6	635.1	78.
C_5H_9N	Isovaleronitrile	83.08	29	772.1	3,231.2	771.9	102.
$C_6H_6N_4$	Triglycolamidic nitrile (tri-(cyanomethyl)amine).[44]	134.09	.....	846.0	3,540.5	.....	198.
$C_6H_7NO_3$	Methyl acetylcyanoacetate (s).	141.07	25	685.0	2,866.7	693.7	78.
$C_6H_9NO_2$	Propyl cyanoacetate	127.08	29	789.0	3,301.9	791.4	78.
$C_7H_9NO_2$	Ethyl cyanoacetylacetate (s)	155.08	31	836.6	3,501.2	850.0	78.
$C_8H_{11}N$	Amyl propiolic nitrile	121.09	43	1,164.2	4,868.7	1,169.7	138.
$C_{11}H_{15}NO$	Cyanocamphor (s)	177.05	57	1,495.4	6,258.3	1,507.8	42.

[42] The above value represents the result of a single determination and should be considered merely as an approximate value.

[43] Considerable difficulty was experienced in the combustion of the compound due to its explosive character.

[44] $N{\equiv}(CH_2C{\equiv}N)_3$.

72. AROMATIC NITRILES

$Q = 26.05 \times N + 16.5nn - 6.5pp$

C_7H_5N	Benzonitrile	103.05	33	865.5	3,622.1	869.6	41.
C_8H_7N	Benzyl cyanide	117.07	39	1,023.5	4,283.4	1,029.4	41.
C_8H_7N	*o*-Tolunitrile	117.07	39	1,030.3	4,311.8	1,022.4	41.
C_8H_5NO	Benzoyl cyanide (s)	131.05	35	940.2	3,934.7	[45] 937.7	78.
C_9H_7NO	Cyanoacetophenone (s)	145.07	.....	1,085.6	4,543.2	.....	78.
C_9H_5N	Phenylpropiolic nitrile	127.04	41	1,117.8	4,674.6	1,111.2	138.
$C_{11}H_7N$	*α*-Naphthonitrile (s)	153.07	51	1,326.2	5,550.2	1,325.5	102.
$C_{11}H_7N$	*β*-Naphthonitrile (s)	153.07	51	1,321.0	5,528.4	1,325.5	102.

[45] See formula for ketonic acids.

73. CARBYLAMINES

(Aliphatic)

$Q = 26.05 \times N + 33.1$

C_2H_3N	Methyl carbylamine	41.03	11	317.4 320.1	1,328.3 1,339.6	319.6	98. 77.
C_3H_5N	Ethyl carbylamine	55.05	17	477.1 480.5	1,996.7 2,010.9	475.9	98. 77.
C_4H_7N	Allyl carbylamine	67.05	21	609.1	2,549.1	593.1	77.
C_4H_7N	Propyl carbylamine	69.06	23	639.6	2,676.7	632.2	77.
C_5H_9N	Isobutyl carbylamine	83.08	29	796.0	3,331.3	788.3	77.
$C_6H_{11}N$	Isoamyl carbylamine	97.10	35	949.5	3,973.7	944.8	77.
C_8H_7N	Benzyl carbylamine	117.07	39	1,046.5	4,379.6	1,045.5	77.[46]

[46] The same article contains also the heats of combustion of double compounds of silver cyanide with methyl, ethyl, propyl, isobutyl, isoamyl carbylamines, $C_3H_3N_2Ag$ to $C_7H_{11}N_2Ag$. The heats of combustion of these compounds are, within the limits of experimental error, rather uniformly about 503 kilojoules larger than the values for the carbylamines.

VIII. TABLES OF DATA—Continued

3. N COMPOUNDS—Continued

74. ISOCYANATES

(Aliphatic)

$Q = 26.05 \times N + 38.1$

Formula	Name	Molecular weight	Number of electrons	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
C_2H_3NO	Methyl isocyanate	57.03	9	269.4	1,127.4	267.6	96.
C_3H_5NO	Ethyl isocyanate	71.05	15	424.5	1,776.5	423.9	96.

75. HYDROXYLAMINE DERIVATIVES

C_6H_7NO	Phenylhydroxylamine [47]	109.06	------	803.7	3,366.7	----------	163.
$C_6H_6N_2O_3$	*m*-Nitrophenylhydroxylamine	154.06	------	765.6	3,204.0	----------	164.

[47] The author (163) does not indicate which isomer is burned.

76. ALIPHATIC NITRO COMPOUNDS

$Q = 26.05 \times N + 13$

CH_3NO_2	Nitromethane	61.03	6	169.4	708.4	169.3	212; cf. 36.
$C_2H_5NO_2$	Nitroethane	75.05	12	322.2	1,348.4	325.6	36.
$C_3H_7NO_2$	Nitropropane	89.07	18	477.9	1,998.6	481.9	212.
$C_{10}H_{14}NO_3$	*α*-Nitrocamphor (s)	197.13	------	1,371.1	5,738.1	----------	42.[48]

[48] This article contains also the heat of combustion of other forms of nitrocamphor.

77. AROMATIC NITRO COMPOUNDS [49]

$Q = 26.05 \times N + 13$ss

$C_6H_5NO_2$	Nitrobenzene	123.05	28	739.2 732.4	3,091.3 3,062.9	742.4 ----------	72. 211.
$C_6H_4N_2O_4$	*o*-Dinitrobenzene (s)	168.05	26	703.2	2,942.9	703.3	33; cf. 72.
$C_6H_4N_2O_4$	*p*-Dinitrobenzene (s)	168.05	26	695.1 692.0	2,908.9 2,893.9	709.3 ----------	33.
$C_6H_4N_2O_4$	*m*-Dinitrobenzene (s) [50]	168.05	26	696.8 694.7	2,916.1 2,905.2	703.3 ----------	33. 211; cf. 72.
$C_6H_3N_3O_6$	1,3,5-Trinitrobenzene (s)	213.05	24	663.7	2,777.6	664.2	33; cf. 72.
$C_6H_3N_3O_6$	1,2,4-Trinitrobenzene (s)	213.05	24	673.7	2,817.4	664.7	72.
$C_{19}H_{13}N_3O_6$	Trinitrotriphenylmethane(s)	379.13	86	2,271.5	9,499.4	2,279.3	179.
$C_{19}H_{13}N_3O_7$	Trinitrotriphenyl carbinol(s)	395.13	84	2,216.7	9,270.2	2,230.7	179.

[49] The heats of combustion of 1,3,5-trinitrobenzene, 2,4,6-trinitro-1-methylnitroaminobenzene, $C_7H_5N_3O_8$, 2,4,6-trinitrotoluene, $C_7H_5N_3O_6$, 2,3,4,6-tetranitro-1-methylnitroaminobenzene, $C_7H_4N_6O_{10}$, ammonium picrate, $C_6H_6N_4O_7$, ammonium salt of hexanitrodiphenylamine, $C_{12}H_5N_7O_{13}$, and trinitroethane, $C_2H_2N_3O_7$, used as explosives, are given by Rubtzov and Sever' yanov, J. Russ. Phys. Chem. Soc., **50**, p. 140; 1918. However, the results are valueless as far as accuracy is concerned, and, since the data in regard to the methods employed are entirely missing, the values have been omitted from this report.

[50] The author (148) claims that by mixing *m*-dinitrobenzene and naphthalene no heat is evolved. Certainly the lower heat of combustion 0.18 per cent obtained for the mixture is meaningless for individual determinations do not check better than 0.5 to 1 per cent.

VIII. TABLES OF DATA—Continued

3. N COMPOUNDS—Continued

78. SUBSTITUTED AROMATIC NITRO COMPOUNDS

$Q = 26.05 \times N + 13ss - 3.5a$

Formula	Name	Molecular weight	Number of electrons	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_7H_7NO_3$	o-Nitrotoluene	137.06	34	897.0	3,751.3	895.2	72.
$C_7H_7NO_3$	p-Nitrotoluene (s)	137.06	34	888.6	3,716.1	895.2	72.
$C_7H_7NO_3$	m-Nitrotoluene	137.06	34	892.9	3,734.1	895.2	72.
				889.9	3,721.6		211.
$C_7H_6N_2O_4$	2,3-Dinitrotoluene (s)	182.06	32	859.6	3,594.9	856.1	211.
$C_7H_6N_2O_4$	2,4-Dinitrotoluene (s)	182.06	32	852.8	3,566.4	856.1	211.
$C_7H_6N_2O_4$	2,5-Dinitrotoluene (s)	182.06	32	855.2	3,576.5	856.1	72.
$C_7H_6N_2O_4$	2,6-Dinitrotoluene (s)	182.06	32	854.3	3,572.7	856.1	72.
$C_7H_6N_2O_4$	3,4-Dinitrotoluene (s)	182.06	32	859.9	3,596.1	856.1	72.
$C_7H_6N_2O_4$	3,5-Dinitrotoluene (s)	182.06	32	853.0	3,567.3	856.1	72.
$C_7H_5N_3O_6$	2,4,6-Trinitrotoluene (s)	227.06	30	820.7	3,432.2	817 0	72.
$C_7H_5N_3O_6$	2,3,4-Trinitrotoluene (s)	227.06	30	832.9	3,483.2	817.0	72.
$C_7H_5N_3O_6$	3,4,6-Trinitrotoluene (s)	227.06	30	825.6	3,452.7	817.0	72.
$C_7H_5N_3O_6$	3,4,5-Trinitrotoluene (s)	227.06	30	828.1	3,463.1	817.0	72.
$C_7H_5N_3O_6$	2,3,5-Trinitrotoluene (s)	227.06	30	823.8	3,445.1	817.0	72.
$C_7H_5N_3O_6$	2,3,6-Trinitrotoluene (s)	227.06	30	825.3	3,451.4	817.0	72.
$C_8H_6N_2O_4$	m-β-Dinitrostyrene (s)	194.06	36	957.4	4,006.7	970.3	226.
$C_8H_6N_2O_4$	p-β-Dinitrostyrene (s)	194.06	36	962.6	4,028.5	970.3	226.
$C_9H_{11}NO_2$	Nitromesitylene (s)	165.10	46	1,204.7	5,038.1	1,200.8	243.[51]
$C_9H_{11}NO_2$	ω-Nitromesitylene (s)	165.10	46	1,194.3	4,994.6	1,208.0	243.
$C_9H_{10}N_2O_4$	Dinitromesitylene (s)	210.10	44	1,175.7	4,916.8	1,161.7	243.
$C_9H_{10}N_2O_4$	ω-o-Dinitromesitylene	210.10	44	[52] 1,155.7	4,830.8	1,161.7	243.
$C_{14}H_9NO_4$	p-Nitrobenzil (s)	255.08	60	1,600.9	6,699.8	1,589.0	8.[53]
$C_{16}H_{11}NO_4$	p-Nitroacetylbenzoin (s)	297.10	70	1,864.3	7,802.1	1,852.5	8.
$C_{21}H_{13}NO_5$	p-Nitrobenzoylbenzoin (s)	359.11	92	2,443.4	10,225.6	2,422.1	8.

[51] All the values by (243) have been corrected according to the method suggested by Swietoslawski, J. Amer. Chem. Soc., 42, p. 1091; 1920.

[52] The author (243) believes that the difference in the heats of combustion of these two isomers, 1.79 per cent, is due to the fact that the compounds were not quite pure.

[53] Details as to procedure employed in obtaining the data are completely lacking in the paper.

79. AROMATIC NITROPHENOLS, PHENETOLES, NITRANILINES, NITROACETANILIDES

$Q = 26.05 \times N + 13ss + 3.5m + 6.5jj + 13kk + 19.5p$

$C_6H_5NO_3$	o-Nitrophenol (s)	139.05	26	689.1	2,881.8	693.8	72.
				687.9	2,878.9		131.
				688.3	2,880.5		210.
$C_6H_5NO_3$	m-Nitrophenol (s)	139.05	26	684.4	2,864.2	693.8	210.
$C_6H_5NO_3$	p-Nitrophenol (s)	139.05	26	686.2	2,869.7	693.8	72.
				688.8	2,882.6		131.
				688.2	2,880.1		210.
$C_6H_4N_2O_5$	2,4-Dinitrophenol (s)	184.05	24	648.0	2,709.9	654.7	72.
$C_6H_3N_3O_7$	2,4,6-Trinitrophenol (s) (Picric acid).	229.05	22	621.1	2,597.4	615.6	72.
				611.8	2,562.8		170.
$C_8H_9NO_3$	o-Nitrophenetole	167.08	38	1,021.2	4,270.7	1,022.4	211.
$C_8H_9NO_3$	m-Nitrophenetole	167.08	38	1,009.2	4,223.5	1,022.4	210.
$C_8H_9NO_3$	p-Nitrophenetole	167.08	38	1,006.0	4,210.1	1,022.4	210.
$C_6H_6N_2O_2$	o-Nitraniline (s)	138.06	29	765.8	3,204.8	771.4	210.
$C_6H_6N_2O_2$	m-Nitraniline (s)	138.06	29	765.2	3,200.1	771.4	211.
$C_6H_6N_2O_2$	p-Nitraniline (s)	138.06	29	761.0	3,187.8	771.4	170.
$C_7H_8N_2O_2$	p-Nitromethylaniline (s)	152.08	35	924.3	3,865.4	934.3	72.
$C_7H_7N_3O_4$	2,4-Dinitromethylaniline (s)	197.08	33	884.5	3,698.9	895.2	72.
$C_7H_6N_4O_6$	2,4,6-Trinitromethylaniline (s).	242.08	31	857.9	3,587.7	856.0	72.
$C_7H_5N_5O_8$	Tetryl (s)	287.08	.....	842.3	3,522.5	.....	72.
$C_8H_7N_5O_8$	Methyltetryl (s) (2,4,6-Trinitro-N-nitroethylaniline).	301.10	.....	1,009.3	4,220.9	.....	72.
$C_8H_8N_2O_3$	o-Nitroacetanilide (s)	180.08	37	973.9	4,075.8	973.3	210.
$C_8H_8N_2O_3$	m-Nitroacetanilide (s)	180.08	37	969.5	4,054.5	973.3	211; cf. 131.
$C_8H_8N_2O_3$	p-Nitroacetanilide (s)	180.08	37	968.2	4,051.9	973.3	210.

VIII. TABLES OF DATA—Continued

3. N COMPOUNDS—Continued

80. AROMATIC NITROALDEHYDES

$Q = 26.05 \times N + 13ss + 13r - 3.5a$

Formula	Name	Molecular weight	Number of electrons	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_7H_5NO_3$	*m*-Nitrobenzaldehyde (s)	151.05	30	800.4	3,349.7	804.0	131.

81. AROMATIC NITRO ACIDS

$Q = 26.05 \times N + 13ss - 3.5a + 13c$

Formula	Name	Molecular weight	Number of electrons	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_7H_5NO_4$	*o*-Nitrobenzoic acid (s)	167.05	28	729.8	3,054.2	738.9	131.
				735.0	3,078.9		151.
$C_7H_5NO_4$	*m*-Nitrobenzoic acid (s)	167.05	28	726.4	3,039.9	738.9	58.
				729.1	3,049.1		151.
$C_7H_5NO_4$	*p*-Nitrobenzoic acid (s)	167.05	28	728.3	3,047.9	738.9	58.
				728.3	3,045.8		151.
$C_9H_7NO_4$	*o*-Nitrocinnamic acid (s)	193.06	38	999.0	4,180.8	1,009.4	226.
$C_9H_7NO_4$	*m*-Nitrocinnamic acid (s)	193.06	38	995.6	4,166.6	1,009.4	226.
$C_9H_7NO_4$	*p*-Nitrocinnamic acid (s)	193.06	38	996.5	4,170.4	1,009.4	226.

82. PHENYLHYDRAZONES AND OSAZONES

The two articles by Ph. Landrieu, Compt. rend., **141**, p. 358; 1905; **142**, p. 540; 1906, contain the heats of combustion of the phenylhydrazones of the following aldehydes and ketones: Acetaldehyde, acetone, diacetyl, furfuraldehyde, benzaldehyde, salicylaldehyde, acetophenone, anisaldehyde, benzophenone, benzoin, benzil; the phenylhydrazones of the following sugars: Arabinose, glucose, galactose, levulose, mannose, maltose, lactose; the osazones of glyoxal, diacetyl, benzil; and of the following sugars: Arabinose, xylose, glucose, levulose, mannose, galactose, maltose, lactose. The data are not included in the tables, for the information given in the above articles in regard to the work is extremely meager, and a careful analysis of the values indicates that they do not form a homogeneous series.

83. ALDOXIMES (ALIPHATIC)

Formula	Name	Molecular weight	Number of electrons	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
C_2H_5NO	Aldoxime (s)	59.05	------	340.6	1,424.4	----------	93.[84]
C_3H_7NO	Acetoxime (s)	73.07	------	490.5	2,051.3	----------	93.

[84] It is of interest to compare these values of (93) with those of (215) for methyl ethyl ketoxime, C_4H_9NO. The former's values appear to be about 0.8 per cent too high.

84. KETOXIMES (ALIPHATIC)

Formula	Name	Molecular weight	Number of electrons	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
C_4H_9NO	Methyl ethyl ketoxime	87.08	------	646.5	2,703.7	----------	215.
				651.0	2,724.4	----------	93.
$C_8H_{17}NO$	Cycloheptyl methyl ketoxime (s).	155.15	------	1,363.5	5,702.2	----------	215.
$C_{10}H_{17}NO$	Camphoroxime (s)	167.15	------	1,480.8	6,197.2	----------	93.

VIII. TABLES OF DATA—Continued

3. N COMPOUNDS—Continued

85. AROMATIC ALDOXIMES AND KETOXIMES

Formula	Name	Molecular weight	Number of electrons	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_6H_5NO_2$	Benzoquinone oxime (*p*-Nitrosophenol).	123.05		713.5	2,985.9		225; cf. 222.
C_7H_7NO	Benzaldoxime (s)	121.07		907.2	3,793.9		93.
C_8H_9NO	Methyl phenyl ketoxime (s)	135.08		1,054.4	4,409.5		93.
$C_{10}H_7NO_2$	α-Naphthoquinone oxime (s) (α-Nitroso-α-naphthol).	173.07		1,163.5	4,868.3		225; cf. 222.
$C_{10}H_7NO_2$	β-Naphthoquinone oxime (s) (β-Nitroso-α-naphthol).	173.07		1,167.4	4,885.6		225; cf. 222.
$C_{10}H_7NO_2$	β-Naphthoquinone oxime (s) (α-Nitroso-β-naphthol).	173.07		1,166.7	4,882.6		225; cf. 222.
	Oxime of opianic anhydride[55]			1,152.3	4,822.4		108.
$C_{10}H_{13}NO_2$	Thymoquinone oxime (s)	179.11		1,331.8	5,573.6		225; cf. 222.
$C_{13}H_{11}NO$	Diphenyl ketoxime (s)	197.10		1,626.8	6,803.3		225; cf. 93.

[55] Stohmann, communicated by Liebermann (Ber., **25**, p. 89; 1892.) Formula and molecular weight not indicated. He does not specify whether the above value refers to constant volume or constant pressure.

86. NITROSAMINES[56]

$C_2H_6N_2O$	Dimethylnitrosamine	74.07		394.5	1,650.9		212.
$C_8H_{10}N_2O$	Ethylphenylnitrosamine (s)	150.10		1,118.4	4,680.5		212.
$C_{12}H_{10}N_2O$	Diphenylnitrosamine (s)	198.10		1,532.6	6,413.9		132.

[56] See also article by Delépine (C. R., **123**, p. 650; 1896) for nitroso and nitro compounds of hexamethylene tetramine.

87. NITRAMINES

$C_2H_6N_2O_2$	Ethylnitramine[57]	90.06		372.5	1,557.8		211.

[57] $CH_3.CH_2.NH.NO_2$.

88. NITROSO COMPOUNDS

$C_6H_4N_2O_4$	Dinitrosoresorcinol (s)	168.05		[58] 582.5	2,437.8		212.
$C_8H_{10}N_2O$	*p*-Nitrosodimethylaniline (s).	150.10		[58] 1,124.7	4,706.9		212; cf. 132.
$C_{12}H_{10}N_2O$	*p*-Nitrosodiphenylamine (s)	198.10		1,626.9	6,385.5		132.

[58] The author (212) gives as the mean value 3,473 cal/g. In his calculation of the molecular heat of combustion he employs 186 as the molecular weight instead of 168.05. The article contains, also, the heats of reaction of a large number of compounds with nitrous acid. For a detailed treatment of this subject consult Ber., **43**, p. 1470; 1910; **44**, p. 2429; 1911.

[59] The author (212) gives also the heat of combustion of nitrosodimethylaniline hydrochloride as 4,687.2 kilo-joules.

89. AZO COMPOUNDS

$C_{12}H_{10}N_2$	Azobenzene (s)	182.10		1,555.2 1,552.6 1,545.9	6,508.5 6,497.6 6,469.6		147. 100. 217.[60]
$C_{12}H_{10}N_2O$	*p*-Hydroxyazobenzene (s)	198.10		1,502.0	6,285.9		101.
$C_{12}H_{11}N_3$	*p*-Aminoazobenzene (s)	197.12		1,574.0	6,587.2		101.
$C_{12}H_{12}N_4$	2,4-Diaminoazobenzene (s) (Chrysoidine).	212.14		1,597.4	6,685.1		101.
$C_{14}H_{14}N_2O_2$	*p*-Azoanisole	242.13		1,796.4	7,517.9		101.
$C_{16}H_{18}N_2O_2$	*p*-Azophenetole (s)	270.16		2,100.0	8,788.5		101.

[60] Undoubtedly the best value is that of (217).

VIII. TABLES OF DATA—Continued

3. N COMPOUNDS—Continued

90. SUBSTITUTED HYDRAZINES

Formula	Name	Molecular weight	Number of electrons	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_6H_8N_2$	Phenylhydrazine (s)	108.08		875.4	3,663.6		100.
				805.4	3,370.6		147.
$C_7H_{10}N_2$	Methylphenylhydrazine (s) (*asym.*).	122.10		1,038.1	4,344.5		100.
$C_{12}H_{12}N_2$	Hydrazobenzene (s)	184.12		1,597.3	6,684.7		100.
				1,598.8	6,690.9		147.

91. DIAZONIUM COMPOUNDS

$C_6H_5N_3O_3$	Benzenediazonium nitrate (s).	167.07		782.6	3,275.2		45.

92. AZOXY COMPOUNDS

$C_{12}H_{10}N_2O$	Azoxybenzene (s)	198.10		1,534.5	6,421.9		101.
				1,530.1	6,403.5		147.
$C_{14}H_{16}N_4O$	*m*-Azoxytoluidine (s)	256.17		1,903.4	7,965.7		101.
$C_{16}H_{18}N_2O_3$	*p*-Azoxyphenetole (s)	286.13		2,098.4	8,781.8		101.
$C_{16}H_{18}N_2O_3$	*o*-Azoxyphenetole (s)	286.13		2,088.0	8,730.3		101.

93. ESTERS OF NITRIC AND NITROUS ACID

$C_2H_5NO_2$	Ethyl nitrite (v)	75.0		332.6	1,390.9		223.
$C_2H_5NO_3$	Ethyl nitrate (v)	91.0		322.4	1,348.3		223.
$C_3H_5N_3O_9$	Trinitroglycerol	227.06		432.4	1,809.6		81.
$C_4H_9NO_2$	Isobutyl nitrite (v)	103.0		644.6	2,695.7		223.

4. HALOGEN AND SULPHUR COMPOUNDS

94. FLUORINE COMPOUNDS

(*a*) FLUORO-HYDROCARBONS (ALIPHATIC)

$C_7H_{15}F$	*n*-Heptyl fluoride	118.12		1,121.5	4,690.1		211.
$C_8H_{17}F$	*n*-Octyl fluoride (from bromide).	132.13		1,271.0	5,315.3		211.
$C_8H_{17}F$	*n*-Octyl fluoride (from iodide).	132.13		[61] 1,266.4	5,296.1		211.

[61] The B. P. of the product prepared from the iodide is 0.6° higher than the one prepared from the bromide. See also Ber., 55, p. 3378; 1922.

(B) FLUORO-HYDROCARBONS (AROMATIC)

C_6H_5F	Fluorobenzene	96.05		747.2	3,124.8		211.
$C_6H_4F_2$	*p*-Difluorobenzene	114.05		706.1	2,952.9		211.
C_7H_7F	*o*-Fluorotoluene	110.05		903.2	3,777.2		211.
C_7H_7F	*p*-Fluorotoluene	110.05		903.0	3,776.3		211.
$C_7H_6F_2$	ω-Difluorotoluene (s)	128.05		856.9	3,583.6		211.
$C_7H_5F_3$	ω-Trifluorotoluene (s)	146.05		810.3	3,388.7		211.
$C_8H_{11}F$	Fluoropseudocumene (s)	138.1		1,208.5	5,053.9		211.

(C) FLUORO-ALCOHOLS (ALIPHATIC)

C_2H_5OF	Fluoroethanol	64.05		290.4	1,214.5		211.
$C_2H_4OF_2$	Difluoroethanol	82.02		245.8	1,027.9		211.

VIII. TABLES OF DATA—Continued

4. HALOGEN AND SULPHUR COMPOUNDS—Continued

94. FLUORINE COMPOUNDS—Continued

(D) FLUORO-PHENOLS

Formula	Name	Molecular weight	Number of electrons	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
C_6H_5OF	*o*-Fluorophenol	112.05		705.8	2,951.7		211.
C_6H_5OF	*m*-Fluorophenol	112.05		696.6	2,913.2		211.
C_6H_5OF	*p*-Fluorophenol (s) (Stable modif., M. P. 48.2°).	112.05		696.6	2,913.2		211.
$C_7H_5OF_3$	Trifluoro-*m*-cresol	162.05		763.4	3,192.5		211.

(E) ESTERS OF FLUORO-ALCOHOLS

$C_4H_7O_2F$	Fluoroethyl acetate	106.05		499.9	2,090.6		211.
$C_4H_6O_2F_2$	Difluoroethyl acetate	124.05		455.5	1,904.9		211.

(F) ETHERS OF FLUORO-ALCOHOLS

C_5H_9OF	Ethyl fluoroallyl ether	104.07		731.0	3,057.0		211.

(G) ETHERS OF FLUORO-PHENOLS

C_9H_9OF	*m*-Fluorophenetol	140.05		1,023.1	4,278.6		211.
C_9H_9OF	*p*-Fluorophenetol	140.05		1,019.9	4,265.2		211.

(H) FLUORO-ACIDS ALIPHATIC

$C_2H_3O_2F$	Fluoroacetic acid (s)	78.02		170.8	714.3		211.
$C_2H_2O_2F_2$	Difluoroacetic acid	96.02		134.6	562.9		211.

(I) FLUORO-ACIDS (AROMATIC)

$C_7H_5O_2F$	*o*-Fluorobenzoic acid (s)	140.05		740.2	3,095.5		211.
$C_7H_5O_2F$	*m*-Fluorobenzoic acid (s)	140.05		737.6	3,084.6		211.
$C_7H_5O_2F$	*p*-Fluorobenzoic acid (s)	140.05		739.7	3,093.4		211.
$C_8H_5O_2F_3$	*m*-ω-Trifluorotoluic acid [61a] (s).	190.05		807.1	3,375.4		211.
$C_9H_7O_2F$	α-Fluorocinnamic acid (s)	166.06		1,013.6	4,238.9		211.

[61a] $m-F_3C-C_6H_4.COOH$.

(J) ESTERS OF FLUORO-ACIDS (ALIPHATIC)

$C_4H_7O_2F$	Ethyl fluoroacetate	106.05		503.1	2,103.9		211.
$C_4H_6O_2F_2$	Ethyl difluoroacetate	124.05		436.5	1,825.4		211.

(K) ESTERS OF FLUORO-ACIDS (AROMATIC)

$C_9H_9O_2F$	Ethyl *p*-fluorobenzoate (s)	168.05		1,060.1	4,433.3		211.
$C_{10}H_9O_2F$	Methyl α-fluorocinnamate (s).	180.05		1,187.5	4,966.1		211.

(L) FLUORO-AMIDES (ALIPHATIC)

C_2H_4ONF	Fluoroacetamide (s)	77.05		250.0	1,045.5		211.
$C_2H_3ONF_2$	Difluoroacetamide (s)	95.05		208.3	871.1		211.

VIII. TABLES OF DATA—Continued

4. HALOGEN AND SULPHUR COMPOUNDS—Continued

94. FLUORINE COMPOUNDS—Continued

(M) FLUORO-AMIDES (AROMATIC)

Formula	Name	Molecular weight	Number of electrons	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_9H_7ONF_2$	Difluoroacetanilide (s)	171.06	------	944.8	3,951.2	----------	211.
$C_9H_5ONF_3$	*m*-Trifluoroacettoluide (s)	203.75	------	1,043.2	4,362.7	----------	211.

(N) FLUORO-AMINES (ALIPHATIC)

$C_2H_3NF_2$	Difluoroethylamine	81.05	------	326.1	1,363.8	----------	211.
$C_4H_7NF_4$	Tetrafluorodiethylamine	145.06	------	566.1	2,367.4	----------	211.

(O) FLUORO-NITRAMINES (ALIPHATIC)

$C_2H_4O_2N_2F_2$	Difluoroethylnitramine (s) (M. P. 22.4°).	126.06	------	290.6	1,215.3	----------	211.

(P) FLUORO-NITROBENZENES

$C_6H_4O_2NF$	*o*-Fluoronitrobenzene	141.05	------	707.5	2,958.8	----------	211.
$C_6H_4O_2NF$	*m*-Fluoronitrobenzene	141.05	------	706.4	2,954.2	----------	211.
$C_6H_4O_2NF$	*p*-Fluoronitrobenzene (s)	141.05	------	703.0	2,939.9	----------	211.
$C_6H_3O_2NF_2$	1,4-Difluoro-2-nitrobenzene	159.04	------	673.1	2,814.9	----------	211.
$C_6H_3O_4N_2F$	2,4-Dinitro-1-fluorobenzene (s).	186.05	------	669.3	2,799.0	----------	211.

(Q) FLUORO-NITROTOLUENES

$C_7H_4O_2NF_3$	*m*-Nitrobenzotrifluoride	191.05	------	771.5	3,226.4	----------	211.

(R) FLUORO-ANILINES

C_6H_6NF	*o*-Fluoroaniline	111.05	------	778.2	3,254.4	----------	211.
C_6H_6NF	*m*-Fluoroaniline	111.05	------	771.1	3,249.8	----------	211.
C_6H_6NF	*p*-Fluoroaniline	111.05	------	782.2	3,271.2	----------	211.

(S) FLUORO-ANILIDES

C_8H_8ONF	*m*-Fluoroacetanilide (s)	153.07	------	978.1	4,090.4	----------	211.
C_8H_8ONF	*p*-Fluoroacetanilide (s)	153.07	------	978.9	4,093.8	----------	211.

(T) FLUORO-NITROPHENOLS AND NITROPHENETOLES

$C_6H_4O_3NF$	3-Nitro-4-fluorophenol (s)	157.04	------	652.8	2,730.0	----------	211.
$C_8H_8O_3NF$	3-Nitro-4-fluorophenetol (s)	185.07	------	981.4	4,104.21	----------	211.

(U) FLUORO-NITRANILINES AND NITRACETANILIDES

$C_6H_5O_2N_2F$	3-Nitro-4-fluoroaniline (s)	156.04	------	736.9	3,081.7	----------	211.
$C_8H_7O_3N_2F$	3-Nitro-4-fluoroacetanilide	198.06	------	936.2	3,915.2	----------	211.

VIII. TABLES OF DATA—Continued

4. HALOGEN AND SULPHUR COMPOUNDS—Continued

95. CHLORINE COMPOUNDS

(A) CHLORINATED HYDROCARBONS [62]

Formula	Name	Molecular weight	Number of electrons	Kg-cals (experimental)	Kilojoules (K. J.)	Kg-cals (calculated to the liquid state)	Literature
CH_3Cl	Methyl chloride (g)	50.5		164.2	686.7		223.
				173.2	724.8		14.
CH_2Cl_2	Methylene chloride (v)	85.0		[63] 106.8	446.9		40.
$CHCl_3$	Chloroform (v)	119.5		70.3	293.9		223.
	Chloroform (liq.)			89.2	373.3		17.
CCl_4	Carbon tetrachloride (v)	154.0		44.5	186.2		17.
	Carbon tetrachloride (liq.)			37.3	156.1		17.
C_2H_5Cl	Ethyl chloride (v)	64.5		316.7	1,324.4		223.
				326.9	1,368.1		14.
$C_2H_4Cl_2$	Ethylene chloride (v)	99.0		271.0	1,133.3		223.
$C_2H_4Cl_2$	Ethylidene chloride (v)	99.0		271.1	1,133.7		223.
	Ethylidene chloride (liq.)			[64] 267.1	1,117.8		40.
C_2Cl_6	Hexachloroethane (s)	237.0		110.0	460.4		17.
C_2H_3Cl	Chloroethylene (v)	62.5		281.5	1,177.2		223.
C_2Cl_4	Tetrachloroethylene	166.0		162.5	680.1		17.
C_3H_7Cl	Propyl chloride (v)	78.5		478.3	2,000.3		223.
$C_3H_6Cl_2$	Dimethyldichloromethane (Acetone chloride) (v).	112.9		427.8	1,789.1		223.
C_3H_5Cl	Chloropropylene (v)	76.5		439.5	1,838.0		223.
C_3H_5Cl	Allyl chloride (v)	76.5		440.8	1,843.4		223.
$C_3H_4Cl_2$	Dichlorotrimethylene	111.0		426.0	1,782.8		36.
C_4H_9Cl	Isobutyl chloride	92.5		635.5	2,657.7		223.
$C_6H_4Cl_2$	*o*-Dichlorobenzene (s)	147.0		671.8	2,811.5		17.
C_6Cl_6	Hexachlorobenzene (s)	285.0		509.0	2,130.2		17.
C_7H_7Cl	Benzyl chloride	126.5		886.4	3,706.9		179.
$C_{10}H_{16}HCl$	Camphene hydrochloride	172.5		1,469.8	6,146.7		32.
$C_{10}H_{16}.2HCl$	Terpilene dihydrochloride	209.0		1,467.7	6,137.9		32.
$C_{10}H_{16}HCl$	Terebenthene hydrochloride (cryst.).	172.5		1,469.2	6,144.2		32.
$C_{13}H_{11}Cl$	Diphenylchloromethane (s)	202.5		1,617.3	6,763.6		179.
$C_{19}H_{15}Cl$	Triphenylchloromethane (s)	278.0		2,348.5	9,821.4		179.

[62] These compounds are not arranged in classes, but are given according to the number of carbon atoms they contain. In view of the relativity large error in the determinations, the molecular weights are all rounded off. All the data except Thomsen's determinations, or unless otherwise indicated, refer to the formation of a dilute solution of hydrochloric acid. Thomsen's determinations are calculated to the production of gaseous hydrogen chloride. No vacuum correction was applied to any of the values. It is impossible to calculate the heats of combustion of these compounds with any degree of precision, for the amounts of water used in the respective combustions are not specified by any of the writers (except Thomsen) and, hence, it is impossible to correct the values for the heat of dilution of the hydrogen chloride formed.

[63] HCl-gas.

[64] HCl-gas.

(B) COMPOUNDS OF C, H, O AND CL (ALIPHATIC)

C_2H_3OCl	Monochloroacetaldehyde	78.5		234.4	980.3		157.
$C_2H_3O_2Cl$	Monochloroacetic acid (s)	94.5		171.0	715.6		36.
$C_2HO_2Cl_3$	Trichloroacetic acid (s)	163.5		92.8	388.4		36.
$C_4H_7O_2Cl$	Ethyl monochloroacetate	122.5		493.9	2,065.5		157.
$C_4H_6O_2Cl_2$	Ethyl dichloroacetate	157.0		463.4	1,937.9		157.

(C) COMPOUNDS OF C, H, O AND CL (AROMATIC)

C_7H_5OCl	Benzoyl chloride	140.5		782.8	3,273.7		157.
$C_7H_5O_2Cl$	*o*-Chlorobenzoic acid (s)	156.5		734.5	3,071.7		157.
$C_7H_5O_2Cl$	*p*-Chlorobenzoic acid (s)	156.5		726.6	3,038.6		157.
$C_7H_4OCl_2$	*o*-Chlorobenzoyl chloride (s)	175.0		741.5	3,100.9		157.
$C_7H_5O_2Cl$	Chlorosalicylaldehyde [65]	156.5		746.3	3,121.0		157.
C_8H_7OCl	*o*-Toluyl chloride (s)	154.5		944.0	3,947.8		157.
$C_8H_4O_2Cl_2$	Phtnalyl chloride (s)	203.0		801.8	3,353.1		157.
$C_9H_9O_2Cl$	Ethyl *o*-chlorobenzoate	184.5		1,065.8	4,457.2		157.

[65] The position of the chlorine atom in the molecule is not given.

VIII. TABLES OF DATA—Continued

4. HALOGEN AND SULPHUR COMPOUNDS—Continued

95. CHLORINE COMPOUNDS—Continued

(D) CHLOROHYDROQUINOLS

Formula	Name	Molecular weight	Number of electrons	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_6H_3O_2Cl$	Chlorohydroquinol (s)	144.5		645.9	2,703.1		225; cf. 222.
$C_6H_4O_2Cl_2$	2,6-Dichlorohydroquinol (s)	179.0		614.1	2,568.2		225; cf. 222.
$C_6H_3O_2Cl_3$	Trichlorohydroquinol (s)	213.5		593.0	2,481.7		225; cf. 222.
$C_6H_2O_2Cl_4$	Tetrachlorohydroquinol (s)	248.0		562.8	2,355.3		225; cf. 222.

(E) CHLOROQUINONES

$C_6H_2O_4Cl_2$	Chloranilic acid (s)	209.0		484.9		2,020.3	225; cf. 222.
$C_6H_3O_2Cl$	Chloroquinone (s)	142.5		616.6		2,580.5	225; cf. 222.
$C_6H_2O_2Cl_2$	2,6-Dichloroquinone (s)	177.0		578.9		2,422.7	225; cf. 222.
$C_6HO_2Cl_3$	Trichloroquinone (s)	211.5		546.4		2,286.7	225; cf. 222.
$C_6O_2Cl_4$	Tetrachloroquinone (s) (Chloranil).	246.0		517.7		2,166.6	225; cf. 222.

(F) CHLORINE COMPOUNDS OF C, H, O, N

C_2H_4ONCl	Chloroacetamide (s)	93.5		242.5	1,014.1		157.
$C_2H_2ONCl_3$	Trichloroacetamide (s)	162.5		165.2	690.9		157.

96. ALKYL BROMIDES[66]

CH_3Br	Methyl bromide (v)	95		184.0	769.5		223.
				180.4	754.9		14.
C_2H_5Br	Ethyl bromide (v)	109.0		340.5	1,423.9		223.
				329.5	1,378.9		14.
C_3H_7Br	Propyl bromide (v)	123.0		497.3	2,079.7		223.

[66] See footnote 62, p. 418, under chlorinated hydrocarbons. The final product of combustion in the case of the bromine derivatives is bromine vapor.

97. IODINE COMPOUNDS[67]

CH_3I	Methyl iodide (v)	142.0		200.5	838.5		223.
	Methyl iodide (liq.)			194.7	814.8		21.
CH_2I_2	Methylene iodide	268.0		178.4	746.6		21.
CHI_3	Iodoform (s)	394.0		161.9	677.6		21.
C_2H_5I	Ethyl iodide (v)	156.0		357.8	1,496.3		223.
	Ethyl iodide (liq.)			356.0	1,489.9		21.
$C_2H_4I_2$	Ethylene iodide (s)	282.0		324.8	1,359.3		21.
C_2I_4	Tetraiodoethylene (s)	534.0		261.6	1,094.8		21.
C_3H_7I	*n*-Propyl iodide	170.0		514.3	2,152.3		21.
C_3H_7I	Isopropyl iodide	170.0		509.1	2,130.6		21.
C_3H_5I	Allyl iodide	168.0		478.3	2,001.7		21.
C_4HNI_4	Tetraiodopyrrol (s) (Iodol)	571.0		503.1	2,105.5		21.
C_6H_5I	Phenyl iodide	264.0		770.7	3,225.4		21.
C_6H_6NI	Iodoaniline	225.0		810.7	3,392.8		170.
$C_7H_5O_2I$	*o*-Iodobenzoic acid (s)	248.0		769.6	3,220.8		21.
C_7H_5OI	Iodosalicylic acid (s)	264.0		706.4	2,956.3		21.
$C_7H_4O_3I_2$	Diiodosalicylic acid (s)	390.0		699.9	2,929.1		21.

[67] It is claimed that all the iodo compounds give upon combustion iodine and only inappreciable amounts of HI or HIO_3. Under the conditions of the experiments solid iodine is always the end product. Individual determinations do not agree better than 0.5 to 1.0 per cent.

VIII. TABLES OF DATA—Continued

4. HALOGEN AND SULPHUR COMPOUNDS—Continued

98. SULPHUR COMPOUNDS [68]

Formula	Name	Molecular weight	Number of electrons	Kg-cal$_{18}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{18}$ (calculated to the liquid state)	Literature
COS	Carbonyl sulphide (g)	60.0		130.5	545.8		223.
CS_2	Carbon disulphide (v)	76.0		257.7	1,077.7		223.
	Carbon disulphide (liq.)	76.0		[69] 246.6	1,032.0		13.
				394.5	1,650.9		17.
CH_4S	Methyl mercaptan (v)	48.0		297.6	1,244.6		223.
CH_4N_2S	Thiourea (s)	76.0		[70] 342.8	1,434.6		130.
C_2H_6S	Ethyl mercaptan (v)	62.0		452.0	1,890.3		223.
	Ethyl mercaptan (liq.)	62.0		517.2	2,164.5		22.
C_2H_6S	Dimethyl sulphide (v)	62.0		455.6	1,905.3		223.
C_2H_3NS	Methyl thiocyanate (v)	73.0		397.4	1,661.9		223.
	Methyl thiocyanate (liq.)			453.1	1,896.2		20.
C_2H_3NS	Methyl isothiocyanate (v) (Methyl mustard oil).	73.0		390.5	1,633.1		223.
	Methyl isothiocyanate (v) Methyl isothiocyanate (s).			442.9	1,853.5		20.
$C_2H_7O_2NS$	Taurine (s)	125.0		382.9	1,602.4		17.
C_3H_5NS	Ethyl thiocyanate	87.0		613.8	2,568.8		20.
C_3H_5NS	Ethyl isothiocyanate (ethyl mustard oil).	87.0		604.1	2,528.2		20.
$C_3H_6O_2N_2S$	Thiohydantoic acid (s)	134.0		498.5	2,086.2		130.
$C_3H_4ON_2S$	Thiohydantoine (s)	116.1		503.0	2,105.1		130.
$C_4H_{10}S$	Diethyl sulphide (v)	90.0		769.2	3,216.8		223.
	Diethyl sulphide (liq.)			829.5	3,471.5		22.
$C_4H_9NS_2$	Dimethyl N-methylcarbimidodithiolate [71]	103.0		969.2	4,056.1		61.
$C_4H_9NS_2$	S-Methyl N-dimethyldithiocarbamate (sol.). [72]	103.0		953.9	3,992.1		61.
$C_4N_9NS_2$	Methyl formothialdine [73]	103.0		964.5	4,036.4		61.
$C_4H_8N_2S$	Thiosinamine (s)	116.0		791.8	3,313.7		20.
C_4H_5NS	Allyl mustard oil	99.0		732.5	3,065.5		20.
	Allyl mustard oil (v)			672.8	2,813.6		223.
C_4H_4S	Thiophene	84.0		670.5	2,806.0		37.
	Thiophene (v)			608.2	2,543.5		223.
$C_5H_{11}NS_2$	Dimethyl N-ethylcarbimidedithiolate. [74]	117.0		1,130.1	4,729.5		61.
$C_5H_{11}NS_2$	S-Ethyl ester N-dimethyldithiocarbamate. [75]	117.0		1,122.0	4,695.6		61.
$C_5H_{10}N_2S_2$	Dimethyl formocarbothialdine (sol.). [76]	130		1,098.4	4,596.8		61.
$C_5H_{10}N_2S_2$	Carbothialdine (sol.) [77]	130.0		1,085.8	4,544.1		61.
$C_5H_{10}N_2S_2$	Pentamethylenediamine disulfine (sol.). [78]	130.0		1,112.7	4,656.7		61.

[68] The data of (223) refer to the formation of gaseous SO_2. All other values, unless otherwise indicated, refer to the production of a dilute solution of sulphuric acid. Cf. the recent paper of A. Mennucci, Rev. facultad. cienc. quim., 2, p. 25; 1924. This author states that complete oxidation of sulphur derivatives to SO_3 does not occur even at 25 atm. with an evolution of 10,000 calories of heat. The results of the different investigators are not comparable and can not be brought to a comparable basis, for the amount of water used in the bombs is not in all cases specified. In view of the relatively large error that may thus be introduced, all molecular weights are given in round numbers, and no vacuum or other corrections have been applied to the values of any investigator except that the usual correction has been applied to work of (223).

[69] Gaseous SO_2.

[70] Bomb contained exactly 25 cm^3 H_2O. Final state of H_2SO_4 corresponds to H_2SO_4. 200 H_2O.

[71] $CH_3.N=C=(SCH_3)_2$.

[72] $(CH_3)_2NC=S-SCH_3$.

[73]

[74] $C_2H_5N=C(SCH_3)_2$.

[75]

[76] $CS_2(CH_2=N-CH_3)_2$.

[77] $CS_2(CH_3C=NH)_2$.

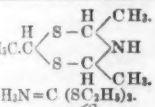
[78]

VIII. TABLES OF DATA—Continued

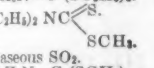
4. HALOGEN AND SULPHUR COMPOUNDS—Continued

98. SULPHUR COMPOUNDS—Continued

Formula	Name	Molecular weight	Number of electrons	Kg-cal$_{15}$ (experimental)	Kilojoules (K. J.)	Kg-cal$_{15}$ (calculated to the liquid state)	Literature
$C_5H_8O_2S$	Tetrahydro-α-thiophenecarboxylic acid (s).	130.2		754.8	3,156.6		185.
$C_5H_4O_2S$	α-Thiophenecarboxylic acid (s).	128.0		646.2	2,702.4		185.
$C_6H_{13}NS_2$	Thialdine (sol) [79]	131.0		1,263.6	5,288.2		61.
$C_6H_{13}NS_2$	Diethyl N-methylcarbimidedithiolate. [80]	131.0		1,289.4	5,396.1		61.
$C_6H_{13}NS_2$	S-Methyl N-diethyldithiocarbamate. [81]	131.0	*	1,271.7	5,322.0		61.
$C_6H_{12}O_4N_2S_2$	Cystine (s)	240.25		[82] 993.9	4,156.5		19.
C_7H_5NS	Phenyl mustard oil	135.0		1,024.3	4,286.7		22.
$C_8H_{11}NS_2$	Dimethyl N-phenylcarbimidedithiolate (sol.). [83]	165.0		1,544.5	6,463.7		61.
$C_{18}H_{14}O_2N_2S$	Benzonaphthoquinone thiazine (s).	322.20		2,278.1	9,533.8		178.

[79] 

[80] $CH_3N{=}C(SC_2H_5)_2$.

[81] 

[82] Gaseous SO_2.

[83] $C_6H_5N{=}C(SCH_3)_2$

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X. INDEX OF COMPOUNDS, BY FORMULA

1. CH COMPOUNDS

Formula	Page	Formula	Page	Formula	Page
CH_4	373	C_8H_{16}	374, 376	$C_{12}H_{12}$	377
C_2H_2	378	C_8H_{18}	373	$C_{14}H_{14}$	378
C_2H_4	376	C_9H_{10}	376	$C_{14}H_{30}$	378
C_2H_6	373	C_9H_{12}	375	$C_{15}H_{14}$	377
C_2H_4	378	C_9H_{14}	378	$C_{16}H_{10}$	378
C_3H_4	374, 376	C_9H_{16}	378	$C_{16}H_{14}$	377
C_3H_6	373	C_9H_{18}	374	$C_{16}H_{34}$	378
C_4H_6	376	$C_{10}H_8$	375	$C_{18}H_{12}$	376
C_4H_{10}	373	$C_{10}H_{10}$	378	$C_{18}H_{16}$	377
C_5H_{10}	374, 376	$C_{10}H_{12}$	376, 377, 378	$C_{18}H_{18}$	376, 377
C_5H_{12}	373	$C_{10}H_{14}$	375, 378	$C_{18}H_{20}$	377
C_6H_6	375, 378	$C_{10}H_{16}$	378	$C_{19}H_{15}$	378
C_6H_8	377	$C_{10}H_{18}$	374, 378	$C_{19}H_{16}$	378
C_6H_{10}	374, 376, 377	$C_{10}H_{20}$	374, 376	$C_{20}H_{12}$	377
C_6H_{12}	374, 376	$C_{10}H_{22}$	373	$C_{20}H_{42}$	378
C_6H_{14}	373	$C_{11}H_{14}$	377	$C_{24}H_{18}$	376
C_7H_8	375	$C_{11}H_{16}$	375	$C_{28}H_{20}$	378
C_7H_{12}	374, 377, 378	$C_{12}H_{10}$	378	$C_{28}H_{30}$	378
C_7H_{14}	374	$C_{12}H_{10}$	375		
C_7H_{16}	373	$C_{12}H_{16}$	377		
C_8H_6	378	$C_{12}H_{18}$	375		
C_8H_8	376, 378	$C_{12}H_{24}$	376		
C_8H_{10}	375	$C_{12}H_{10}$	376		
C_8H_{12}	377	$C_{12}H_{12}$	375		
C_8H_{14}	377, 378	$C_{14}H_{10}$	376		

X. INDEX OF COMPOUNDS, BY FORMULA—Continued

2. CHO COMPOUNDS

Formula	Page
CH_2O	384
$\frac{1}{n}(CH_2O)_n$	384
CH_2O_2	389
CH_4O	379, 384
C_2 $C_2H_2O_2$	384, 399
$C_2H_2O_2.H_2O$	390
$C_2H_4O_4$	391
C_2H_4O	384, 385
$C_2H_4O_2$	389, 399
$C_2H_4O_3$	390
C_2H_6O	379, 382
$C_2H_6O_2$	380
C_3 C_3H_4O	379, 385
$C_3H_4O_2$	390
$C_3H_4O_3$	390
$C_3H_4O_4$	391
$C_3H_6O_3$	392
C_3H_8O	379, 384, 385
$C_3H_8O_2$	383, 389, 399, 401
$C_3H_8O_3$	390, 400
C_3H_8O	379, 382
$C_3H_8O_2$	380, 383
$C_3H_8O_3$	380
C_4 $C_4H_2O_3$	397
$C_4H_2O_4$	393
$C_4H_4O_2$	390
$C_4H_4O_3$	397
$C_4H_4O_4$	393
C_4H_8O	382, 385
$C_4H_8O_2$	383, 385, 390, 396, 403
$C_4H_8O_3$	397
$C_4H_8O_4$	391, 400
$C_4H_8O_5$	392
$C_4H_8O_6$	392
C_4H_8O	382, 385
$C_4H_8O_2$	385, 389, 399, 401
$C_4H_8O_3$	390, 399
$C_4H_{10}O$	379, 380, 382
$C_4H_{10}O_2$	383
$C_4H_{10}O_3$	380, 383
$C_4H_{10}O_4$	380
C_5 $C_5H_4O_2$	385
$C_5H_4O_3$	390, 397
$C_5H_6O_2$	401
$C_5H_6O_3$	397
$C_5H_8O_4$	393, 396
C_5H_8O	387
$C_5H_8O_2$	385, 390, 396, 403
$C_5H_8O_3$	390, 399
$C_5H_8O_4$	391, 400
$C_5H_8O_7$	392
$C_5H_{10}O$	379, 384, 385
$C_5H_{10}O_2$	379, 381, 389, 399, 401
$C_5H_{10}O_3$	401, 402
$C_5H_{10}O_5$	388
$C_5H_{12}O$	379, 380
$C_5H_{12}O_2$	383
$C_5H_{12}O_4$	380
C_5 $C_5H_{12}O_5$	380
C_6 $C_6H_4O_2$	386
C_6H_4O	382
$C_6H_6O_2$	382
$C_6H_6O_3$	382
$C_6H_6O_6$	393
$C_6H_8O_2$	390
$C_6H_8O_3$	398
$C_6H_8O_4$	393, 396, 400
$C_6H_8O_6$	391
$C_6H_8O_7$	392
$C_6H_8O_7.H_2O$	392
$C_6H_{10}O$	382, 385, 387
$C_6H_{10}O_2$	382, 385, 390, 399
$C_6H_{10}O_3$	398, 401
$C_6H_{10}O_4$	383, 391, 400, 402
$C_6H_{10}O_5$	388, 399
$(C_6H_{10}O_5)x$	389
$C_6H_{10}O_6$	399, 400
$C_6H_{10}O_8$	392
$C_6H_{12}O$	379, 380, 384, 385
$C_6H_{12}O_2$	381, 389, 401
$C_6H_{12}O_3$	385
$C_6H_{12}O_5$	380, 388
$C_6H_{12}O_5.H_2O$	388
$C_6H_{12}O_6$	380, 388
$C_6H_{14}O$	379, 380
$C_6H_{14}O_2$	380, 382, 383
$C_6H_{14}O_6$	381
C_7 $C_7H_4O_7$	397
C_7H_6O	385
$C_7H_6O_2$	385, 386, 393
$C_7H_6O_3$	394
$C_7H_6O_4$	394
$C_7H_6O_5$	394
$C_7H_6O_8$	396
C_7H_8O	379, 382, 383
$C_7H_8O_2$	382
$C_7H_{10}O_2$	396
$C_7H_{10}O_3$	398
$C_7H_{10}O_4$	393, 396, 399, 400
$C_7H_{10}O_5$	400
$C_7H_{12}O$	379, 387
$C_7H_{12}O_2$	382, 396, 401
$C_7H_{12}O_3$	401
$C_7H_{12}O_4$	391, 400, 402
$C_7H_{12}O_6$	396
$C_7H_{12}O_7$	399
$C_7H_{14}O$	379, 380, 385, 386
$C_7H_{14}O_2$	381, 389, 401, 403
$C_7H_{14}O_6$	383
$C_7H_{14}O_7$	388
$C_7H_{16}O$	379, 380
$C_7H_{16}O_2$	383
$C_7H_{16}O_7$	381
C_8 $C_8H_4O_3$	398
$C_8H_6O_2$	399
$C_8H_6O_3$	385
$C_8H_6O_4$	394, 395
C_8H_8O	386
$C_8H_8O_2$	393, 394, 400
$C_8H_8O_3$	385, 393, 394, 400
$C_8H_8O_4$	397
$C_8H_8O_5$	400
$C_8H_{10}O$	382, 383
$C_8H_{10}O_2$	383
$C_8H_{10}O_3$	398
$C_8H_{10}O_4$	397, 402
$C_8H_{12}O$	387
$C_8H_{12}O_2$	390, 397, 401
$C_8H_{12}O_3$	398
$C_8H_{12}O_4$	397, 400, 401
$C_8H_{14}O$	379, 380, 387
$C_8H_{14}O_2$	381, 397
$C_8H_{14}O_3$	402
$C_8H_{14}O_4$	383, 391, 400, 402
$C_8H_{14}O_6$	392, 402
$C_8H_{14}O_8$	399
$C_8H_{16}O$	379, 380, 386
$C_8H_{16}O_2$	381, 389
$C_8H_{18}O$	379, 380
C_9 C_9H_6O	385
$C_9H_6O_2$	394
$C_9H_6O_4$	395
C_9H_8O	379, 384, 385, 387
$C_9H_8O_2$	394, 402
$C_9H_8O_3$	393, 394
$C_9H_8O_4$	395
$C_9H_{10}O_2$	381, 393, 394, 402
$C_9H_{10}O_3$	400, 402
$C_9H_{12}O$	382, 383
$C_9H_{12}O_3$	385
$C_9H_{14}O$	386, 387
$C_9H_{14}O_2$	390, 397, 399
$C_9H_{14}O_4$	381, 400
$C_9H_{14}O_6$	383
$C_9H_{14}O_7$	400
$C_9H_{16}O$	379, 380, 387
$C_9H_{16}O_4$	391, 400
$C_9H_{18}O$	379, 380
$C_9H_{18}O_2$	389
$C_9H_{20}O$	380
$C_9H_{20}O_2$	383
C_{10} $C_{10}H_6O_2$	386
$C_{10}H_6O_4$	386
$C_{10}H_6O_8$	395
$C_{10}H_8O$	382, 386
$C_{10}H_8O_2$	400
$C_{10}H_8O_3$	398
$C_{10}H_8O_4$	386, 394, 396
$C_{10}H_{10}O$	386
$C_{10}H_{10}O_2$	383, 394, 400
$C_{10}H_{10}O_3$	395
$C_{10}H_{10}O_4$	396, 399, 401
$C_{10}H_{10}O_5$	394
$C_{10}H_{10}O_6$	394
$C_{10}H_{12}O$	383
$C_{10}H_{12}O_2$	381, 383, 386, 393, 403
$C_{10}H_{12}O_3$	403
$C_{10}H_{12}O_4$	400

X. INDEX OF COMPOUNDS, BY FORMULA—Continued

2. CHO COMPOUNDS—Continued

Formula	Page
$C_{10}H_{14}O$	382, 383, 387
$C_{10}H_{14}O_2$	382
$C_{10}H_{14}O_3$	398
$C_{10}H_{14}O_4$	400
$C_{10}H_{14}O_5$	401
$C_{10}H_{16}O$	385, 387
$C_{10}H_{16}O_2$	390, 397, 399, 402
$C_{10}H_{16}O_3$	397, 398
$C_{10}H_{16}O_4$	381, 397, 401
$C_{10}H_{18}O$	379, 380
$C_{10}H_{18}O_2$	397
$C_{10}H_{18}O_4$	392, 400, 402
$C_{10}H_{20}O$	379, 380
$C_{10}H_{20}O_2$	389
$C_{10}H_{22}O$	382
$C_{10}H_{22}O_5$	380
C_{11} $C_{11}H_8O_2$	393
$C_{11}H_{10}O$	386
$C_{11}H_{10}O_2$	395, 402
$C_{11}H_{10}O_4$	395
$C_{11}H_{12}O$	386
$C_{11}H_{12}O_3$	395
$C_{11}H_{12}O_5$	399
$C_{11}H_{14}O_2$	383, 403
$C_{11}H_{14}O_3$	403
$C_{11}H_{14}O_5$	401
$C_{11}H_{16}O$	384
$C_{11}H_{16}O_2$	402
$C_{11}H_{16}O_4$	401
$C_{11}H_{16}O_5$	401
$C_{11}H_{18}O_2$	390, 402
$C_{11}H_{18}O_3$	399, 402
$C_{11}H_{18}O_4$	401
$C_{11}H_{20}O_2$	390
$C_{11}H_{20}O_4$	392, 400
$C_{11}H_{22}O$	380
$C_{11}H_{22}O_2$	389
$C_{11}H_{24}O_2$	383
C_{12} $C_{12}H_6O_3$	398
$C_{12}H_8O_{12}$	395
$C_{12}H_8O_4$	395
$C_{12}H_{10}O_2$	400
$C_{12}H_{10}O_4$	386, 396
$C_{12}H_{12}O$	386
$C_{12}H_{12}O_3$	395
$C_{12}H_{12}O_6$	401
$C_{12}H_{12}O_{12}$	397
$C_{12}H_{14}O_2$	402, 403
$C_{12}H_{14}O_3$	395, 400, 402, 403
$C_{12}H_{14}O_4$	384
$C_{12}H_{16}O_2$	381, 384, 403
$C_{12}H_{16}O_3$	384
$C_{12}H_{18}O$	384
$C_{12}H_{18}O_2$	402
C_{12} $C_{12}H_{18}O_3$	388
$C_{12}H_{20}O_2$	403
$C_{12}H_{20}O_3$	398
$C_{12}H_{20}O_6$	383
$C_{12}H_{20}O_7$	402
$C_{12}H_{22}O_2$	383
$C_{12}H_{22}O_3$	398
$C_{12}H_{22}O_4$	383, 392, 400
$C_{12}H_{22}O_{11}$	388
$C_{12}H_{22}O_{11}.H_2O$	388
$C_{12}H_{24}O_2$	389
C_{13} $C_{13}H_{10}O$	386
$C_{13}H_{10}O_3$	403
$C_{13}H_{12}O$	379
$C_{13}H_{14}O$	386
$C_{13}H_{14}O_4$	381
$C_{13}H_{16}O_3$	395
$C_{13}H_{20}O$	386, 387
$C_{13}H_{24}O_2$	383
$C_{13}H_{24}O_4$	392
C_{14} $C_{14}H_8O_2$	386
$C_{14}H_8O_3$	386
$C_{14}H_8O_4$	387
$C_{14}H_8O_5$	387
$C_{14}H_8O_8$	387
$C_{14}H_{10}O_2$	382, 386
$C_{14}H_{10}O_3$	385, 398
$C_{14}H_{10}O_4$	386
$C_{14}H_{12}O_2$	386, 395, 403
$C_{14}H_{12}O_3$	395
$C_{14}H_{12}O_4$	403
$C_{14}H_{14}O_2$	381
$C_{14}H_{16}O$	386
$C_{14}H_{16}O_4$	381
$C_{14}H_{18}O$	379
$C_{14}H_{18}O_3$	395
$C_{14}H_{20}O_8$	402
$C_{14}H_{22}O_8$	402
$C_{14}H_{26}O_2$	398
$C_{14}H_{28}O_2$	389
C_{15} $C_{15}H_{10}O$	386
$C_{15}H_{14}O_2$	403
$C_{15}H_{20}O_6$	403
$C_{15}H_{28}O_6$	403
C_{16} $C_{16}H_{10}O_3$	398
$C_{16}H_{12}O_3$	398
$C_{16}H_{16}O_4$	396
$C_{16}H_{16}O_2$	384, 395, 403
$C_{16}H_{22}O_{11}$	388
$C_{16}H_{32}O_2$	389
$C_{16}H_{34}O$	379
C_{17} $C_{17}H_{14}O$	386
$C_{17}H_{16}O_3$	395, 403
$C_{17}H_{18}O_2$	403
C_{18} $C_{18}H_{14}O_3$	398
$C_{18}H_{16}O_2$	387
$C_{18}H_{16}O_4$	396, 401
$C_{18}H_{18}O_{12}$	401
$C_{18}H_{26}O_6$	403
$C_{18}H_{32}O_2$	390
$C_{18}H_{32}O_{16}$	389
$C_{18}H_{32}O_{16}H_2O$	389
$C_{18}H_{32}O_{16}.5H_2O$	389
$C_{18}H_{34}O_2$	390
$C_{18}H_{36}O_2$	389, 403
C_{19} $C_{19}H_{15}O_2$	375
$C_{19}H_{16}O$	380
$C_{19}H_{18}O_4$	381
$C_{19}H_{20}O_3$	396
$C_{19}H_{36}O_4$	392
C_{20} $C_{20}H_{14}O_4$	403
$C_{20}H_{20}O_4$	381, 401
$C_{20}H_{22}O_4$	402
$C_{20}H_{40}O_2$	389
C_{21} $C_{21}H_{16}O$	380, 386
$C_{21}H_{16}O_2$	382, 384
$C_{21}H_{18}O_2$	386
$C_{21}H_{22}O_4$	381
C_{22} $C_{22}H_{18}O$	384
$C_{22}H_{40}O_2$	390
$C_{22}H_{42}O_2$	390
$C_{22}H_{44}O_2$	389
$C_{22}H_{44}O_4$	390
C_{23} $C_{23}H_{18}O_4$	381
$C_{23}H_{20}O$	384
C_{24} $C_{24}H_{20}O_4$	381
$C_{24}H_{20}O_6$	403
$C_{24}H_{20}O_8$	396
$C_{24}H_{22}O$	384
$C_{24}H_{42}O_{21}$	389
$C_{77}+C_{77}H_{46}O$	379
$C_{28}H_{22}O_3$	398
$C_{28}H_{38}O_{19}$	388
$C_{32}H_{30}O_3$	396
$C_{32}H_{64}O_2$	403
$C_{39}H_{74}O_6$	403
$C_{43}H_{86}O_6$	403
$C_{47}H_{88}O_8$	403
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3. N COMPOUNDS

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CH_5N	404
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C_2H_3N	409, 410
C_2H_3NO	409, 411
$C_2H_3NO_3$	406
$C_2H_4N_2O_2$	406
C_2H_5NO	406, 413
$C_2H_5NO_2$	405, 411, 415
$C_2H_5NO_3$	415
$C_2H_6N_2O$	414
$C_2H_6N_2O_2$	414
C_2H_7N	404
$C_2H_8N_2.H_2O$	404
C_3 $C_3H_2N_2$	409
$C_3H_2N_2O_2$	408
$C_3H_3N_2Ag$	410
$C_3H_3NO_2$	409
$C_3H_4N_2O$	409
$C_3H_4N_2O_2$	408
$C_3H_4N_2O_4$	406
C_3H_5N	409, 410
C_3H_5NO	409, 411
$C_3H_5NO_3$	406
$C_3H_6N_2O_2$	415
$C_3H_6N_2O_3$	406
$C_3H_6N_2O_3$	406
C_3H_7N	404
C_3H_7NO	406, 413
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$C_3H_7NO_3$	405
$C_3H_8N_2O$	406
C_3H_9N	404
C_4 C_4N_2	410
$C_4H_2N_2O_4$. H_2O	408
$C_4H_4N_2$	410
$C_4H_4N_2O_2$	408
C_4H_5N	408, 410
$C_4H_5NO_2$	409, 410
$C_4H_5N_2Ag$	410
$C_4H_5N_3$	410
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$C_4H_6N_2O_2$	408
$C_4H_6N_4O_2$	408
C_4H_7N	410
$C_4H_7NO_2$	407
$C_4H_7NO_4$	406
$C_4H_7N_3O$	407
$C_4H_8N_2O_2$	407
$C_4H_8N_2O_3$	406
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$C_4H_9N_3O_3$	407
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$C_5H_4N_4O$	408
$C_5H_4N_4O_2$	408
$C_5H_4N_4O_3$	408
C_5H_5N	408
$C_5H_5N_3O$	408
$C_5H_6N_2$	410
$C_5H_6N_2O_2$	408
$C_5H_6N_2O_3$	408
$C_5H_6N_4O_4$	408
$C_5H_7NO_2$	410
$C_5H_7NO_4$	409
$C_5H_7N_2Ag$	410
$C_5H_7N_3O_3$	408
$C_5H_8N_2O_3$	408
$C_5H_8N_2O_3$	406
$C_5H_8N_4O_3$	408
C_5H_9N	410
$C_5H_9NO_4$	406
$C_5H_{10}N_2O_2$	407
$C_5H_{11}N$	404, 408
$C_5H_{11}NO$	407
$C_5H_{11}NO_2$	406
$C_5H_{11}NO_6$	392
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$C_6H_4N_2O_5$	412
$C_6H_5NO_2$	411, 414
$C_6H_5NO_3$	412
$C_6H_5N_3O_3$	415
$C_6H_6N_2O_2$	412
$C_6H_6N_2O_3$	411
$C_6H_6N_4$	408, 410
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$C_6H_8N_2$	405, 415
$C_6H_9NO_2$	410
$C_6H_9NO_4$	409
$C_6H_9NO_6$	406
$C_6H_9N_2Ag$	410
$C_6H_{10}N_2O_2$	406
$C_6H_{11}N$	410
$C_6H_{11}N_3O_4$	406
$C_6H_{12}N_2O_3$	406
$C_6H_{12}N_4$	408
$C_6H_{13}NO_2$	406
$C_6H_{13}NO_6$	392
$C_6H_{15}N$	404
C_7 C_7H_5N	410
$C_7H_5NO_3$	413
$C_7H_5NO_4$	413
$C_7H_5N_3O_6$	412
$C_7H_6N_2O_2$	412
$C_7H_6N_2O_4$	412
$C_7H_6N_4O_6$	412
C_7H_7NO	407, 414
$C_7H_7NO_2$	412
$C_7H_7N_3O_4$	412
$C_7H_8N_2O$	407
$C_7H_8N_2O_2$	412
$C_7H_8N_4O_2$	408
C_7H_9N	404, 405, 408
C_7H_9NO	405
$C_7H_9NO_3$	410
$C_7H_{10}N_2$	415
$C_7H_{11}N_3Ag$	410
$C_7H_{13}NO_3$	406
$C_7H_{14}N_2O_4$	407
C_7 $C_7H_{13}N$	404
$C_7H_{17}N$	404
C_8 C_8H_5NO	410
$C_8H_5NO_2$	408, 409
$C_8H_6N_2O_4$	412
$C_8H_6N_4O_8$. $2H_2O$	408
C_8H_7N	408, 410
$C_8H_7NO_2$	408
$C_8H_7N_5O_8$	412
$C_8H_8N_2O_3$	412
$C_8H_8N_6O_6$	408
C_8H_9NO	407, 414
$C_8H_9NO_2$	406
$C_8H_9NO_3$	412
$C_8H_{10}N_2O$	414
$C_8H_{10}N_4O_2$	408
$C_8H_{11}ClN_2O$	414
$C_8H_{11}N$	405, 410
$C_8H_{12}N_2O_3$	408
$C_8H_{13}NO$	407
$C_8H_{14}N_4O_5$	406
$C_8H_{16}N_2O_3$	406
$C_8H_{16}N_2O_4$	407
$C_8H_{17}N$	409
$C_8H_{19}N$	404
C_9 C_9H_7N	410
C_9H_7N	409
C_9H_7NO	407, 410
$C_9H_7NO_4$	413
C_9H_9N	409
$C_9H_9NO_3$	407
$C_9H_{10}N_2O_4$	412
$C_9H_{11}N$	408
$C_9H_{11}NO$	407
$C_9H_{11}NO_2$	406, 412
$C_9H_{11}NO_3$	406
$C_9H_{13}N$	404, 405
$C_9H_{13}NO$	407
$C_9H_{15}N_2O_5$	406
$C_9H_{17}NO$	413
C_{10} $C_{10}H_7NO_2$	414
$C_{10}H_8N_2O_3$	408
$C_{10}H_9N$	405, 409
$C_{10}H_9NO_4$	409
$C_{10}H_{11}NO_3$	407
$C_{10}H_{11}NO_4$	407
$C_{10}H_{13}N$	409
$C_{10}H_{13}NO_2$	407, 414
$C_{10}H_{13}NO_6$	392
$C_{10}H_{14}N_2$	409
$C_{10}H_{15}N$	405
$C_{10}H_{15}NO_3$	411
$C_{10}H_{17}NO$	413
$C_{10}H_{19}N$	404
$C_{10}H_{21}N$	404
C_{11} $C_{11}H_7N$	410
$C_{11}H_{11}NO_4$	409
$C_{11}H_{13}NO_3$	407
$C_{11}H_{15}NO$	410
$C_{11}H_{15}NO_6$	392
C_{12} $C_{12}H_9N$	409
$C_{12}H_{10}N_2$	414
$C_{12}H_{10}N_2O$	414, 415
$C_{12}H_{11}N$	405
$C_{12}H_{11}N_3$	414
$C_{12}H_{12}N_2$	405, 415

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$C_{12}H_{12}N_4$	414
$C_{12}H_{14}N_4O_6$	408
$C_{12}H_{14}N_4O_8$	408
$C_{12}H_{22}N_2O_2$	406
$C_{12}H_{27}N$	404
$C_{13}H_{11}NO$	407, 414
$C_{13}H_{12}N_2O$	407
$C_{14}H_9NO_4$	412
$C_{14}H_{14}N_2O_2$	414
$C_{14}H_{15}N$	404
$C_{14}H_{16}N_4O$	415
$C_{15}H_{13}N$	404
$C_{16}H_{10}N_2O_2$	409
$C_{16}H_{11}NO_2$	407
$C_{16}H_{11}NO_3$	412
$C_{16}H_{12}N_2O_4$	408
$C_{16}H_{13}N$	405
$C_{16}H_{13}NO_3$	407
$C_{16}H_{15}NO_3$	407
$C_{16}H_{15}N_2O_2$	407
$C_{16}H_{18}N_2O_2$	414
$C_{16}H_{18}N_2O_3$	415
$C_{17}H_{19}NO_3H_2O$	409
$C_{18}H_{15}N$	405
$C_{18}H_{21}NO_3H_2O$	409
$C_{19}H_{13}N_3O_6$	411
$C_{19}H_{13}N_3O_7$	411
$C_{19}H_{19}N_3O$	405
$C_{19}H_{21}NO_3$	409
$C_{20}H_{21}NO_4$	409
$C_{20}H_{27}NO_{11}$	409
$C_{21}H_{13}NO_5$	412
$C_{21}H_{21}N$	404
$C_{21}H_{23}N_3O_2$	409
$C_{23}H_{23}NO_7$	409
$C_{23}H_{26}N_2O_4$	409
$C_{23}H_{27}NO_8 \cdot 2H_2O$	409

4. HALOGEN COMPOUNDS

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Br	
CH_2Br	419
C_2H_5Br	419
C_3H_7Br	419
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CCl_2	418
$CHCl_3$	418
CH_2Cl_2	418
CH_3Cl	418
C_2Cl_4	418
C_2Cl_6	418
$C_2HCl_3O_2$	418
$C_2H_2Cl_2NO$	419
C_2H_3Cl	418
C_2H_3ClO	418
$C_2H_3ClO_2$	418
C_2H_4ClNO	419
$C_2H_4Cl_2$	418
C_2H_5Cl	418
$C_3H_4Cl_2$	418
C_3H_5Cl	418
$C_3H_6Cl_2$	418
C_3H_7Cl	418
$C_4H_6Cl_2O_2$	418
$C_4H_7ClO_2$	418
C_4H_9Cl	418
$C_6Cl_4O_2$	419
C_6Cl_6	418
$C_6HCl_3O_2$	419
$C_6H_2Cl_2O_2$	419
$C_6H_3Cl_2O_4$	419
$C_6H_3Cl_4O_2$	419
$C_6H_3ClO_2$	419
$C_6H_3Cl_3O_2$	419
$C_6H_4Cl_2$	418
$C_6H_4Cl_2O_2$	419
$C_6H_5ClO_2$	419
$C_7H_4Cl_2O$	418
C_7H_5ClO	418
$C_7H_5ClO_2$	418
C_7H_7Cl	418
$C_8H_4Cl_2O_2$	418
C_8H_7ClO	418
$C_9H_9ClO_2$	418
$C_{10}H_{17}Cl$	418
$C_{10}H_{18}Cl_2$	418
$C_{18}H_{11}Cl$	418
$C_{19}H_{15}Cl$	418
F	
$C_2H_3F_3O_2$	416
$C_2H_5F_2NO$	416
$C_2H_5FO_2$	416
C_2H_4FNO	416
$C_2H_4F_2N_2O_2$	417
$C_3H_4F_2O$	415
$C_3H_5F_2N$	417
C_3H_5FO	415
$C_4H_6F_2O_2$	416
$C_4H_7F_4N$	417
$C_4H_7FO_2$	416
C_5H_9FO	416
$C_6H_3FN_2O_4$	417
$C_6H_5F_2NO_2$	417
$C_6H_4F_2$	415
$C_6H_4FNO_2$	417
$C_6H_4FNO_3$	417
C_6H_5F	415
$C_6H_5FN_2O_2$	417
C_6H_5FO	416
C_6H_6FN	417
$C_7H_4F_2NO_2$	417
$C_7H_5F_3$	415
$C_7H_5FO_2$	416
$C_7H_6F_2O$	416
$C_7H_6F_2$	415
C_7H_7F	415
$C_7H_{15}F$	415
$C_8H_5F_3O_2$	416
$C_8H_7FN_2O_2$	417
$C_8H_7F_2NO$	417
C_8H_8FNO	417
$C_8H_8FNO_2$	417
C_8H_8FO	416
$C_8H_{17}F$	415
$C_9H_7FO_2$	416
$C_9H_8F_2NO$	417
$C_9H_9FO_2$	416
$C_9H_{11}F$	415
$C_{10}H_9FO_2$	416
I	
CHI_3	419
CH_2I_2	419
CH_3I	419
C_2I_4	419
$C_2H_4I_2$	419
C_2H_5I	419
C_3H_5I	419
C_3H_7I	419
C_4HI_4N	419
C_6H_5I	419
C_6H_6IN	419
$C_7H_5IO_2$	419
$C_7H_5IO_3$	419
$C_7H_4I_2O_3$	419

5. S COMPOUNDS

Formula	Page
COS	420
CS_2	420
CH_4N_2S	420
CH_4S	420
C_2H_3NS	420
C_2H_6S	420
$C_2H_7NO_3S$	420
$C_2H_4N_2OS$	420
C_3H_5NS	420
$C_3H_6N_2O_2S$	420
C_4H_4S	420
C_4H_5NS	420
$C_4H_5N_2S$	420
$C_4H_6NS_2$	420
$C_4H_{10}S$	420
$C_5H_4O_2S$	421
$C_5H_9O_2S$	421
$C_5H_{10}N_2S_2$	420
$C_6H_{11}NS_2$	420
$C_6H_{12}N_2O_4S_2$	421
$C_6H_{13}NS_2$	421
C_7H_5NS	421
$C_9H_{11}NS_2$	421
$C_{18}H_{14}N_2O_2S$	421

LABORATORY CORROSION TESTS OF MILD STEEL, WITH SPECIAL REFERENCE TO SHIP PLATE

By Henry S. Rawdon

ABSTRACT

Prompted by the claim that the ship plates of the *Leviathan* have shown evidence in service of outstanding superior corrosion resistance, a series of corrosion tests of mild steels, including some *Leviathan* and other ship plate, was made by the wet-and-dry and the continuous-immersion methods in sea-salt solutions. The steels varied in copper content from a trace to over 0.60 per cent. No differences in corrosion rate were obtained, indicating marked superior corrosion resistance of any of the compositions used. The differences in corrosion behavior observed were those resulting from difference in the test methods employed. The corrosion rate in the wet-and-dry test decreased as the surface film was built up but was always much higher than that for simple immersion. The laboratory test results have not confirmed in any way whatsoever the claims made for the *Leviathan* plate for unusual superior corrosion resistance.

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I. INTRODUCTION

The statement has frequently been made that the steel ship plate used in the construction of the hull of the *Leviathan* has shown in service a marked superiority in its resistance to corrosion by sea water to that shown by other ship plate. Several years ago the results of comparative tests of some of the original steel plates from the *Leviathan* hull and some steel-plate attachments to the hull, added at the time the ship was used for transport duty in the World War, were reported by Waterhouse.[1] A marked difference in the appearance of the original German steel plates and the added plates, which were of English manufacture, noted when after five years'

[1] G. B. Waterhous, Tests of Steel Plates of the *Leviathan*, Iron Trade Rev., 75, p. 229; 1924.

service the ship was drydocked, was the reason for carrying out these tests. Waterhouse states:

> * * * over five years elapsed between drydocking at Liverpool and at South Boston, during which time no attention or care could be given to the hull plates. Nevertheless, it was found that the bottom was in perfectly clean condition, the hull being free from marine growths, pitting, and corrosion. While the ship was at Liverpool five years before, a skeg of English steel plates was riveted to the stern for carrying a part of the rigging for the paravane or other gear, a mine-sweeping device invented, supplied, and installed by the British Government. In contradistinction to the plates of the hull this skeg, or paravane gear, was found to have been very badly attacked by continuous submersion in the sea water without attention for over five years.

On the basis of the tests carried out, Waterhouse was unable to assign a definite reason for the difference in the corrosion behavior of the two types of ship plate. Possible reasons, which he suggested, for the superiority of the German material were "the presence of a comparatively high percentage of copper and a marked banded structure whereby after moderate corrosion low-carbon layers would be exposed to the sea water." The English steel used for comparison, which was severely corroded during the five years' service, was stated to have the appearance of ordinary acid open-hearth steel with no "marked characteristics to distinguish it from ordinary plate except that copper was present in moderate amount." The copper contents of the two steels given by Waterhouse were 0.169 and 0.134 per cent, respectively, for the *Leviathan* plate and the comparison plate of English manufacture.

The importance which has been attached to the reports of the outstanding superior quality of the *Leviathan* ship plate with respect to corrosion resistance is attested by the fact that within the past two years a large American oil-refining company specified that in the construction of a tanker, which was being built in a foreign shipyard, ship plate similar to that used for the hull of the *Leviathan* should be used.

Other cases of alleged superior corrosion resistance of steel when used in contact with sea water have been reported to the Bureau of Standards from time to time. A recent example of this was some copper-bearing steel piling of foreign manufacture submitted by the Bureau of Yards and Docks, United States Navy Department, the claim being made by the company which furnished this material that the results of 15 years' service in tropical waters indicated a useful life of at least 50 years for this material under the conditions used.

The importance of the question whether or not differences in corrosion resistance of the magnitude illustrated by the cases cited above can be demonstrated in the laboratory is obvious without further discussion. In order to obtain information on this point, corrosion tests of these steels, together with a number of comparison steels,

were carried out. The results of these tests form the basis of this report.

It may be well to emphasize that these tests were not planned with the aim of showing whether or not the claims which have been made concerning the superior corrosion resistance of these steels were true. In fact, it is extremely doubtful whether this question could be definitely answered by the results of laboratory tests alone. However, if the results with a series of materials in the laboratory with corrosion tests, based upon the essential features of the service for which the materials are to be used, show no important or significant differences in the behavior of such materials, the conclusion would seem to be justified that, if marked differences in behavior are noted in service, the underlying cause for such differences should be sought for outside of the material itself. In other words, the composition of the materials would not seem to be the controlling factor in the matter.

II. MATERIALS AND METHODS

1. MATERIALS

Through the cooperation of the Merchant Fleet Corporation of the United States Shipping Board, the United States lines, and the Navy Department two pieces of ship plate (1⅛ and ⅞ inch thick, respectively), which had been removed from the hull of the *Leviathan* in 1924, were secured from the Boston Navy Yard. The sample of copper-bearing steel piling (⅜-inch thick) submitted by the Navy Department has already been mentioned. Samples of ship plate (5/16 and 7/16 inch thick) manufactured by the Vitkovice Steel Works (Vitkovice Mines, Steel & Ironworks Corporation, Vitkovice, Czechoslovakia) for the construction of the oil tanker referred to were secured by the kind cooperation of the oil-refining company for whom this ship was being built.

In addition, a number of other steels were used. Since the copper content of the *Leviathan* steel had been suggested by Waterhouse [2] as possibly having an important bearing on the alleged unusual behavior of this steel in service, the comparison steels were chosen so as to represent a rather wide range in copper content. Most of these were taken from the series of steels used by committee A–5 of the American Society for Testing Materials in the weather-exposure tests of steel sheet.[3] These materials, though not in the form of ship plate, were chosen because their corrosion behavior under various conditions of exposure had already been very carefully observed. The compositions of the different steels used are summarized in Table 1.

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[1] See footnote 1, p. 431.

[3] Report of Committee A–5 on Corrosion of Iron and Steel, Proc. Am. Soc. Test. Mtls.; 1918–1928, inclusive.

TABLE 1.—*Composition of steels used in the corrosion tests*

Designation of material	Nature of material	Composition						
		C	Mn	P	S	Si	Cu	Other elements
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
L [1]	Leviathan hull plate	0.15	0.43	0.088	0.078	0.01	0.13	As 0.04.
V [1]	Ship plate, Vitkovice Steel Works.	.21	.46	.039	.041	.02	.23	As 0.024.
P [1]	Steel piling, Navy Department	.16	.73	.056	.034	.01	.23	As 0.013.
SS [2]	Low-copper pure iron	.015	.02	.007	.022	Tr.	.03	
H	Copper-bearing basic open-hearth steel.	.07	.39	.016	.027	.004	.24	
II	Copper-bearing bessemer steel	.06	.37	.095	.066	.006	.25	
OO	Low-copper open-hearth steel	.11	.38	.010	.026	.005	.03	Ni. Tr.
C	Copper-bearing pure iron	.015	.028	.006	.036	.003	.195	
ZZ 712	Special (noncommercial) copper-bearing steels.	.06	.39	.045	.043	Tr.	.31	
Z 709		.05	.40	.042	.042	Tr.	.47	
Z 702		.08	.43	.057	.059	Tr.	.63	
Z 7		.065	.35	.112	.047		.022	
ZZ 715 [2]		.08	.40	.061	.053	Tr.	.36	
1,261 [1]	Commercial copper-bearing iron sheet.	.02	.11	.005	.010	< .01	.53	Mo 0.08. As 0.015.

[1] Analysis by H. A. Bright, associate chemist, and C. P. Larrabee, assistant chemist, Bureau of Standards.

[2] Materials SS to ZZ 715, inclusive, were from the series of steels used by committee A–5, A. S. T. M., the designations used above are those of committee A–5, and the compositions given are those reported by this committee.

Rectangular specimens, 2 by 3½ inches and 2½ by 4 inches, were used for the corrosion tests. The thickness of the specimens varied according to the material from which they were taken. In the case of the sheet the specimens were 2 by 3½ inches, and the full thickness of the sheet was used. In the other cases specimens 2½ by 4 inches ⅛ inch thick were machined from the plate, the specimens being taken so as to represent the material at various distances below the surface in the case of the *Leviathan* plate. The surface area of a specimen was slightly more than 14 square inches (90 cm²) and 20 square inches (129 cm²) for each of the two sizes.

In order to avoid any effect of strain upon the corrosion behavior, the specimens were annealed before being corroded. It is recognized that this does not represent commercial practice, but it was considered necessary in these tests in order that it would be possible to tell whether or not any marked differences in corrosion behavior which might be observed could properly be attributed to composition differences.

The specimens, stacked together in order to minimize oxidation during heating, were annealed in an electrically heated furnace in which a small flame of illuminating gas was burned during the annealing. The specimens were maintained for one hour at 750° C. (1,380° F.) and were allowed to cool in the furnace. The surface of the annealed specimens was cleaned by slight pickling in dilute sulphuric acid (approximately 5 per cent by weight).

2. CORROSION TEST METHODS

A solution of sea salt in distilled water, of the same concentration as that which is often reported for "average" sea water (35 g per liter), was used for the corrosion tests. Some comparison tests were also made with a solution of sodium chloride of the same concentration.

Two methods of applying the solution to the specimens were used. In one the specimens, which were suitably spaced in a supporting rack made of glass rod so that they were not in contact with other specimens or with the sides of the container, were kept immersed in the solution. An enameled cast-iron container having a capacity of slightly less than 2 liters was used. Approximately 1.7 liters of the solution was used in each container with 12 or 15 specimens. During the test the amount of solution was maintained constant by the addition of water to replace that lost by evaporation.

In the second method, the "wet-and-dry" test, the specimens were repeatedly immersed by an automatic device in the solution, the specimens being held in glass racks which were automatically lowered into the solution at regular intervals (15 minutes) and then withdrawn into the air. The apparatus used for this test has been described and illustrated previously.[4] The weight of each specimen before being corroded was determined and also at the close of the test after the rust coating had been removed and the specimen cleaned, washed, and dried.

III. RESULTS

1. CLEANING OF SPECIMENS

No difficulty, whatsoever, was experienced in cleaning the specimens after being corroded by the continuous-immersion method. The surface could very easily be wiped free from any of the brown flocculent corrosion product which formed. This was not true, however, of the specimens corroded by the wet-and-dry method. In this case a hard, firmly adhering scale was formed which could be removed only with difficulty. Prolonged soaking of the specimens in a warm solution of ammonium citrate (approximately 10 per cent by weight) was necessary. It was often found expedient to allow the specimens to remain in this solution for 24 hours or so. Even after such a treatment vigorous scrubbing with a stiff bristle or wire brush was required in order to clean the surface completely. The rather wide "scatter" of the points in Figures 1 and 2, representing the results for this wet-and-dry corrosion test, is undoubtedly to be

[4] H. S. Rawdon and E. C. Groesbeck, Effect of the Testing Method on the Determination of Corrosion Resistance, B. S. Tech. Paper No. 367; 1928.

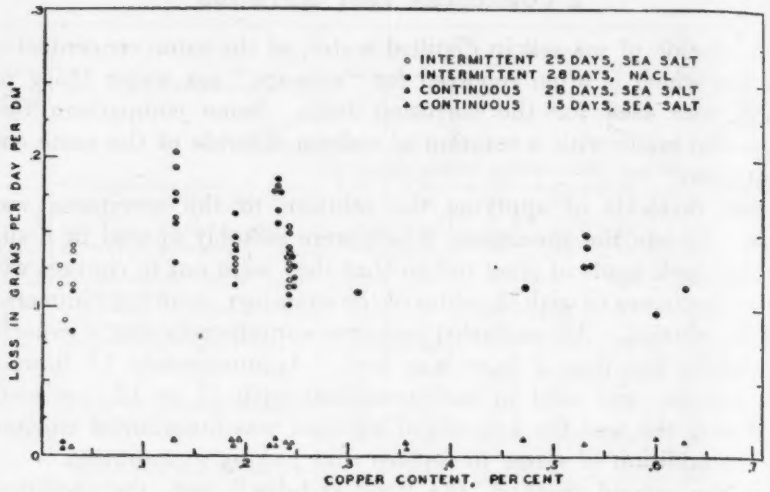
○ INTERMITTENT 25 DAYS, SEA SALT
● INTERMITTENT 28 DAYS, NACL
● CONTINUOUS 28 DAYS, SEA SALT
▲ CONTINUOUS 15 DAYS, SEA SALT
LOSS IN GRAMS PER DAY PER DM²
COPPER CONTENT, PER CENT

FIG. 1.—*Relative corrosion behavior of mild steels of varying copper content when corroded by continuous immersion and by intermittent immersion (wet-and-dry tests)*

The solutions contained 35 g of salt per liter. The specimens of *Leviathan* ship plate, 0.13 per cent copper; the specimens of Vitkovice steel plate, 0.23 per cent copper; and the specimens of special steel piling, 0.23 per cent copper, show no marked superiority in their behavior. In most cases, each point plotted represents several samples. For simplicity and clarity, only the average has been given.

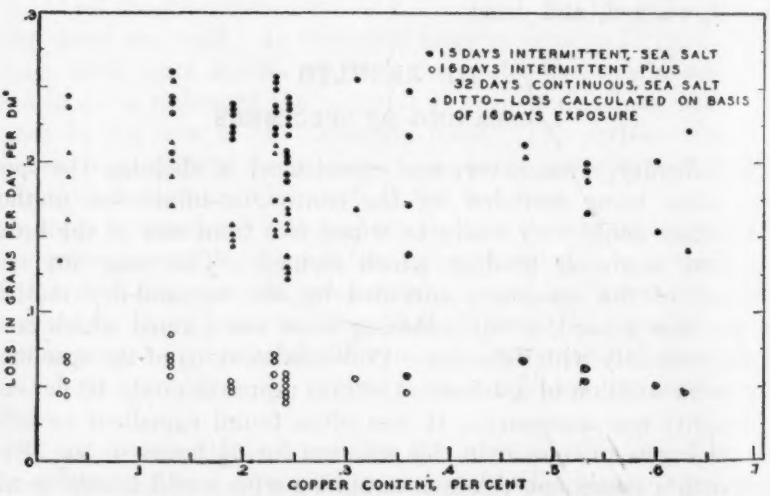
● 15 DAYS INTERMITTENT, SEA SALT
○ 16 DAYS INTERMITTENT PLUS 32 DAYS CONTINUOUS, SEA SALT
▲ DITTO— LOSS CALCULATED ON BASIS OF 16 DAYS EXPOSURE
LOSS IN GRAMS PER DAY PER DM²
COPPER CONTENT, PER CENT

FIG. 2.—*Corrosion behavior of mild steels of varying copper content when corroded by the wet-and-dry method in a solution of sea salt, 35 g per liter*

Two corrosion rates of the specimens subjected to the combined attack of 16 days' corrosion by the wet-and-dry method and 32 days in simple immersion are given. These have been calculated on the basis of the 48-day period and the 16-day period, respectively.

attributed in part to the method used for obtaining a surface free from any of the corrosion scale.

The behavior of the various steels under corrosion is summarized graphically in Figures 1 and 2. The comparison of the corrosion behavior of the different steels has been made on the basis of the loss of weight occurring during the "runs." The corrosive attack in all cases was decidedly uniform in character, only very slight indications of pitting being noticed in any case. The surface of most of the samples corroded by the repeated immersion method showed a very slight "grooving," the direction of grooving being parallel to the flow of the solution as it drained off the specimen when it was withdrawn from the bath. Evidently this effect is to be attributed to the method of wetting the surface and indicates nothing characteristic of the steel. Nothing of this kind was shown by specimens of the same steel which were corroded by the simple immersion method.

Since all of the materials are essentially the same in density, the loss of weight can be used to represent the comparative behavior of the materials just as well as the depth of penetration or thickness of the metal layer removed.

IV. DISCUSSION

It is very evident from the results in Figure 1 that the method by which the corrosive attack was brought about had a far greater influence upon the apparent corrosion resistance of the various steels used in these tests than the copper content or any other feature in the composition had. All of the steels which were used behaved practically the same when subjected to corrosion by simple immersion as measured by the loss in weight per unit area of surface per day. No difference was observed in the corrosive attack of a sodium chloride solution as compared with the attack produced by a solution of sea salt of the same concentration. The corrosive attack under the conditions of simple immersion used was very slight indeed as compared to that occurring when samples of the same steels were corroded by the wet-and-dry or repeated-immersion method. In neither case did variations in the copper content of the steels, up to 0.60 per cent at least, appear to affect the corrosion resistance of the steels to any marked extent.[5]

The corrosion rate for the steels when corroded by the intermittent immersion method depends upon the length of the test period used. Evidently in the tests of this kind the rate of attack slowly decreases as the test period is prolonged. This is shown by a comparison of the results of the 15-day run (fig. 2) and a 25-day run in a solution of sea salt (fig. 1). These tests were carried out at the same time at

[5] This is in general agreement with the results of submerged corrosion tests of copper-bearing steel obtained by committee A-5, Corrosion of iron and steel, Am. Soc. Test. Matls., Proc. Am. Soc. Test. Matls., 24 to 28; 1924-1928, inclusive.

room temperature, and the conditions in each were practically identical. It will be noticed, however, that the corrosion rate computed for the 15-day run (fig. 2) was decidedly higher, on the whole, than the rate computed for the 25-day run (fig. 1). This is in accord with the well-known fact that whenever the products of corrosion form an adherent and continuous covering on a metal they constitute a more or less effective barrier against subsequent corrosive attack. Figure 2 also shows the results obtained when a set of specimens, after being subjected to the wet-and-dry test for 16 days, were then immersed continuously in the solution for 32 days. The average corrosion rate for any of these specimens as based upon the 48 days constituting the entire test period was relatively low. The corrosion rate calculated for the period of 16 days, the assumption being made that little or no corrosion occurred after the surface scale had been built up during the initial 16-day period of repeated immersion, was, of course, higher. The corrosion rates based upon the 16-day period, however, are in fair agreement with those of a 15-day run with repeated immersion made independently of the other series.

The scale which formed on the surface of steel when corroded by the wet-and-dry method consisted largely of the magnetic oxide of iron. On the specimens used for these tests the surface coating of the corrosion products, though brown on the outside and also in some cases immediately adjacent to the metal, was for the greater part black in color and was strongly attracted by a magnet when dry. As stated above, the scale adhered very firmly to the steel and could be removed only with difficulty. In the series of tests summarized in Figure 2, in which the specimens were corroded first by the method of repeated immersion for 16 days and then allowed to remain immersed in the solution for 32 days, it was noted that although the scale was still firmly adherent and apparently afforded protection to the underlying steel against further corrosion it could be removed from the specimen much more readily than that from specimens which had been corroded for 16 days by the repeated-immersion method alone. In speculating as to the probable behavior in service of steel which, prior to continuous immersion in sea water, had been corroded in such a manner as to result in the building up of an adherent surface scale it would seem, on the basis of these results, that the coating would in time become less adherent and might eventually flake from the surface.

The examination of samples of corrosion scale which formed on some of the *Leviathan* plates in service and which were removed at the time the ship was dry-docked (1928) showed that the scale formed under service conditions was very similar in appearance to that formed in the laboratory tests. Some of the samples, however, were only slightly magnetic.

The scale which was formed in the wet-and-dry test was essentially the same on all of the steels. Attempts to vary the character of the scale by carrying out the test while the samples were strongly illuminated by the light from a carbon-arc lamp, a set of comparison samples being corroded in the dark, were indecisive. No difference in the visual appearance of the scale formed under these two conditions could be noted. The results of some recent tests in another connection, however, indicate that the solution which is used to wet the surface may have a marked influence on the physical character of the scale. The coating which formed on wrought iron in wet-and-dry corrosion tests carried out with tap water was found to be much more adherent to the metal than the coating formed in similar tests with a solution of sea salt (35 g per liter).

Concerning the practical aspects of the tests, it may be stated that the results of the tests made have not confirmed in any respect the claims which have been advanced concerning the superior corrosion-resistant properties of some of these steels when used as ship plate for marine service. All of the steels used behaved in all essential respects the same when corroded in the same manner. The differences in corrosion rate shown by the tests were due entirely to the different test methods used.

As a result of the inspection of the hull of the *Leviathan* made during the summer of 1928 it was reported to the Bureau of Standards by the Merchant Fleet Corporation of the United States Shipping Board that—

> There was very little corrosion evident, and the entire hull was in excellent shape with the exception of small areas around the propellers.
>
> The plates which had been renewed at the Boston Navy Yard approximately seven years ago were inspected, and no difference was noted between the condition of these plates and the condition of the original plates.

It may be concluded, therefore, that the difference in the corrosion resistance reported by Waterhouse for the *Leviathan* plate and the comparison steel does not necessarily indicate superior corrosion resisting properties for the *Leviathan* plate. A satisfactory alternative explanation can be based upon the quite widely different conditions which would be expected to obtain in service for the two materials. Any projecting attachments on the hull of a vessel would be subjected to conditions quite different in many respects from those applying to the hull. In particular, the mechanical or "cavitation" effect of the water would be more severe on both paint and metal, and in all probability the effect of aeration on corrosion would be more pronounced also. Either of these would, in large measure, account for more pronounced attack of the steel attachments as compared with the attack of hull plates.

V. SUMMARY

1. Laboratory corrosion tests in solutions of sea salt and sodium chloride by total immersion ("submerged corrosion") and by repeated immersion ("wet-and-dry corrosion") showed no important differences in the corrosion behavior of a series of steels for either method of attack which could be considered as significant of variations in composition, especially variations in the copper content, which in the series used ranged from practically nil to somewhat more than 0.60 per cent. No pronounced pitting or roughening of the surface occurred as a result of either method of testing other than a very slight grooving which paralleled the lines of flow of the solution in the draining off of the specimen as it was withdrawn from the solution in the wet-and-dry test.

2. The corrosion rate (loss of weight per unit surface area per day) was very uniform for all the steels for submerged corrosion, and this rate of attack was decidedly lower than that for repeated immersion in the same solution for the duration of these tests. During submerged corrosion a brown, flocculent corrosion product which could be very easily removed from the specimens formed.

3. When corroded by the wet-and-dry or repeated-immersion method a firmly adherent hard scale formed over the surface which was removed only with considerable difficulty. As a consequence of the protection afforded by this scale, the corrosion rate decreased as the test period was prolonged. All of the steels used behaved similarly in this respect.

4. The results of the tests carried out do not confirm or substantiate in any way the claims which have been made for the outstanding superior corrosion resistance for some of the steels when used in marine service; for example, ship plate. It is believed that differences in the service conditions, the importance of which has apparently not been fully appreciated, will account satisfactorily for the alleged difference in the corrosion behavior of these steels.

The author very gratefully acknowledges his indebtedness to C. E. Eggenschwiler, junior scientific aid, who by his earnest endeavor has assisted very materially in obtaining the results reported here.

WASHINGTON, November 6, 1928.

RP43

LEAST RETINAL ILLUMINATION BY SPECTRAL LIGHT REQUIRED TO EVOKE THE "BLUE ARCS OF THE RETINA" [1]

By Deane B. Judd

ABSTRACT

Interest in the "blue arcs of the retina," first described by Purkinje, has recently been renewed by Ladd-Franklin, who establishes (in a series of papers) to a high degree of probability the theoretical views of Druault. Druault suggested (and later, independently, Ladd-Franklin also) that the blue arcs are due to the emission of light by the fibers of the optic nerve that pass over the surface of the retina. It has been repeatedly mentioned by Ladd-Franklin and others (Druault, Troland, Amberson, Ellis) that the blue arcs are obtained more easily with red light than with a stimulus of any other color. This suggests that the origin of the nerve activity causing the blue arcs lies in the retinal cones rather than in the rods, since the rods are relatively insensitive to red light.

The blue-arc phenomenon has been tentatively linked by the author with a certain phase (called the Purkinje phase, or Bidwell's "ghost") of the periodic afterimage following brief stimulation by light of the extrafoveal retina. The Purkinje phase undoubtedly depends on the action of the rods; hence, the two phenomena which are quite similar in some respects would differ in origin if the blue arcs were really initiated by cone action.

As a check, then, on the origin of the nerve activity producing them, the blue arcs were aroused by pure spectral light (2° circular field), the retinal illumination being subsequently reduced until the blue arcs no longer appeared. In this way the retinal illumination required to evoke the blue arcs has been determined as a function of wave length for the author's right eye.

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[1] Presented in part before the annual meeting (November, 1927) of the Optical Society of America in Washington.

I. INTRODUCTION

The "blue arcs of the retina," known since Purkinje's account of them in 1825, have attracted considerable recent attention.[2] When the macular[3] region of the retina is stimulated by a patch of light (observers have usually used a circle or vertical band), the subject reports not only the image of this stimulus, but usually also two "blue arcs."[4] These arcs correspond quite exactly to the position of the nerve fibers which extend across the inner surface of the retina from the stimulated area to the exit point of the optic nerve ("blind spot").[5] It is universally agreed[6] that activity of these nerve fibers in some way causes them to become visible as the "blue arcs of the retina." H. Gertz proposed to account for the arcs by secondary stimulation of neighboring retinal structures through (1) an external circuit of, or (2) induction by, the action currents set up by the primary stimulus. This sort of explanation (by secondary electric stimulation) has been accepted by Troland, Amberson, Ellis, and Davis. There is some uncertainty as to which structure is to be thought of as being affected by the secondary electric stimulus, whether it be the nerve fibers parallel to those primarily excited (Amberson),[7] the ganglion cells of those fibers (Amberson),[8] the nerve fibers (bipolar cells) perpendicular to them (Troland),[9] or the rods and cones themselves (H. Gertz; Davis).

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[2] Zeeman, Zs. f. Psych. u. Physiol. d. Sinnesorgane, **6,** p. 233; 1894. Siethoff, Zs. f. Psych. u. Physiol. d. Sinnesorgane, **14,** p. 375; 1897. Tscherning, Klin. Monatsbl. f. Augenheilk., **36,** p. 223; 1898; Ann. de la Policlin. de Paris, 1898; Encyclopédie française d'ophthalmologie, III, p. 228; 1904. Charpentier, Compt. Rend. d. l. Soc. d. Biol. (ser. 2), **8,** p. 765; 1885. Thomsen, Skand. Arch. f. Physiol., **37,** p. 1; 1918. O. Gertz, Hosp.-Tid., Københ. (R), **5,** pp. 7, 1197; 1914. H. Gertz, Ueber autoptische Wahrnehmung der Sehtätigkeit der Netzhaut, Skand. Archiv. f. Physiol., **19,** pp. 381–408; 1907; ibid, **21,** pp. 315–350; 1909. Also Ueber entoptische Wahrnehmung des Actionsstroms der Netzhautfasern, Zentralbl. f. Physiol., 19, pp. 229–233; 1905. J. C. Hubbard, A Curious Secondary Visual Phenomenon Resulting from a Stimulation of the Macular Region, Psych. Bull., **7,** pp. 196–199; 1910. A. Druault, Sur un Phénoméne Entoptique en Rapport avec le trajet des fibres optiques dans la rétine (phénomène des arcs), J. de Physiologie et de Pathologie générale, **16,** p. 649; 1914. L. T. Troland, The "All or None" Law in Visual Response, J. Opt. Soc. Am., **4,** pp. 160–185; 1920. An Entoptic Phenomenon Demonstrating the Optic Impulse, Psych. Bull., **17,** p. 55; 1920. W. R. Amberson, Secondary Excitation in the Retina, Amer. J. Physiol., 69, pp. 354–370; 1924. Christine Ladd-Franklin, J. Opt. Soc. Am. and Rev. Sci. Inst., **12,** p. 494; 1926; ibid, **14,** p. 474; 1927; Proc. Nat. Acad. of Sci., **12,** p. 413; 1926; Science, **66,** p. 239; 1927; ibid, **67,** p. 162; 1928; Comptes Rendus, **185,** p. 584; 1927; J. Opt. Soc. Am. and Rev. Sci. Inst., **16,** p. 333; 1928. F. W. Ellis, Secondary Excitation of the Retina and the Variation of the Intensity of the Resulting Sensation, Am. J. Physiol., **82,** p. 290; 1927. The Nature of the Stimulus which Excites the Blue Arcs of the Retina and Related Phenomena, Am. J. Physiol., **84,** p. 485; 1928. H. Davis, Theory of "Visible Radiation" from an Excited Nerve Fiber, Science, **67,** p. 69; 1928.

[3] If Amberson's results are correct (loc. cit., p. 359), only those portions of the macular region which contain rods are effective in producing the blue arcs. Stimulation of the central rod-free area does not do it.

[4] Often called "blue" inaccurately as an abbreviation; the color is a slightly reddish blue.

[5] Amberson (loc. cit., p. 361), confirming this conclusion previously based on shape and approximate size only, has shown for 10 observers that the length of the arcs corresponds to the papillo-foveal distance.

[6] Except Siethoff (loc. cit.), whose views are shown to be untenable by Druault (loc. cit., p. 650) and, later, by Amberson (loc. cit., p. 357) also.

[7] Amberson, loc. cit., p. 367.

[8] Amberson, loc. cit., p. 368.

[9] Troland, loc. cit., p. 167.

In 1914 there appeared a paper by Druault, apparently until now unknown in this country,[10] which opposes grave objections to the secondary electric stimulation theory and which proposes another explanation, namely, that the fibers are visible because they emit physical light. Ladd-Franklin (1920–1926) independently formulated similar objections and also independently proposed the same alternative explanation. She added, however, the conclusive argument that the blue arcs must result from action upon the light-sensitive substance in the rods and cones by physical light, because (for many subjects) the blue arcs are followed by a chromatic residual image (dark greenish yellow).[11] Only stimulation of the light-sensitive substance in the cones by physical light yields a chromatic residual image; electric stimulation does not do it nor stimulation by pressure.[12]

Though, to be sure, acceptance of the theory of visible radiation proposed by Druault, even following Ladd-Franklin's definitive argument in its favor, has been far from universal; nevertheless, the writer has been inclined to accept it, persuaded partly by confirmation obtained in connection with the Purkinje phase of the periodic afterimage following momentary stimulation of the extra-foveal retina by light.[13] It was found that a number of the properties of the Purkinje phase, which have hitherto remained unaccounted for, yielded perfectly to the same explanation that had been proposed (by Druault and Ladd-Franklin) for the blue arcs, namely, that active nerve fiber gives off physical light. In the case of the Purkinje phase we assume that light is emitted by the nerve structures (bipolar cells, etc.), leading from the outer surface of the retina (rod-cone layer) to the inner surface.

But there are two outstanding differences between the two phenomena. If we are to ascribe the Purkinje phase entirely or partly to the same sort of bioluminescence, or production of visible radiation to which we ascribe the blue arcs, it would be well to examine these differences.

First, the blue arcs are, at best, very faint, as would befit phenomena of secondary retinal stimulation. The Purkinje phase by the right choice of experimental conditions can be made very vivid and striking. Detailed images nearly as distinct and brilliant as the primary image often appear.[14] The explanation of the brilliance of the Purkinje phase may lie in the fact that the nerve structure to which bioluminescence is attributed lies perhaps one-third to one-fifth as far from the rod-cone layer as the fibers on the inner surface of the retina;

[10] Sent to Mr. Priest in response to a request for reprints of papers on the subject of color vision.

[11] Ladd-Franklin, Sci., **66**, p. 240; 1927. H. Gertz, Skand. Archiv., **19**, p. 404; 1907.

[12] Ladd-Franklin, Sci., **66**, p. 240; 1927.

[13] D. B. Judd, A Quantitative Investigation of the Purkinje Afterimage., Am. J. Psych., **38**, pp. 507–533; 1927.

[14] Judd, loc. cit., p. 519.

hence, for the same *brightness* of radiating surface (active nerve fiber) the rod-cone illumination would be much higher than that causing the blue arcs, the Purkinje phase appearing, on that account, much more *brilliant*.[15] Another alternative explanation (perhaps less satisfying) is to say that the observed Purkinje phase is the sum of two components: (1) The contribution of physical light from contiguous active nerve fiber and (2) the contribution of a nature similar to that of the other phases (Hering phase, third positive phase, negative phases, etc.).[16] This explanation is favored by the fact that the properties of the Purkinje phase which are particularly suggestive of emission of physical light are observed under conditions which do not give a brilliant image but which give an image of brilliance comparable to that of the blue arcs.

Second, the Purkinje phase seems to arise from initial activity of the rods. It does not appear in the fovea, and it does not appear following a primary stimulus of pure spectral red light (say, of 650 mμ). On the other hand, the blue arcs, according to Ellis,[17] though contrary to Amberson,[18] appear "best defined and most intense when the stimulating image falls within the fovea." Furthermore, a red primary stimulus not only evokes the blue arcs successfully, but a red light is the best for demonstration of the blue arcs.[19] From these facts the conclusion is suggested that the blue arcs are due to nerve activity initiated by the retinal cones.[20]

It is the purpose of the present paper to give the results of an experiment designed to show whether cone activity initiates the nerve activity responsible for the blue arcs (as the facts just presented suggest) or whether rod activity initiates it (as Amberson has concluded and as the connection of the blue arcs with the Purkinje phase in other respects suggest).

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[15] The use of the terms "brightness" and "brilliance" is as given in the report of the colorimetry committee. See J. Opt. Soc. Am. and Rev. Sci. Inst., **6**, p. 534; 1922.

[16] Consult in this connection: Hartline (Am. J. of Physiol., **73**, p. 600; 1925) who has succeeded in demonstrating that one of the positive afterimage phases (probably the third positive phase) is correlated with a rise in electric potential in the retina.

[17] Ellis, loc. cit., p. 290; 1927.

[18] Amberson, loc. cit., p. 359.

[19] Thus, Druault (loc. cit., p. 649) says, "Le phénomène peut s'observer avec n'importe quelle lumière, mais plus facilement avec la lumière rouge." Ellis says (loc. cit., p. 293; 1927) "Red light is ordinarily employed to excite the blue arcs, and it is especially well adapted for this purpose * * *." Ladd-Franklin (loc. cit. Nat. Acad. Sci.) recommends for demonstration of the blue arcs "A simple band of bright red light thrown upon a screen in a dark room." Hubbard (loc. cit., p. 196) suggests diffuse light from a "ruby lamp" for demonstration of the blue arcs, and further says, "The brushes (arcs) appear very faint at the extreme red. They increase in brightness as the eye travels up the spectrum and are brightest in the orange red * * *."

[20] In spite of this evidence, Amberson (loc. cit., p. 359), from regional considerations alone, concludes that, "* * * the effects under discussion are rod, rather than cone, phenomena, in the sense that the primarily excited and conducting fibers must arise from ganglion cells on the rod pathways in the region of primary stimulation."

As the title of this paper indicates, the experiment consisted of determining the least retinal illumination by spectral light required to evoke the blue arcs. It is apparent that if the rods initiate the nerve activity responsible for the blue arcs a pure spectral stimulus of wave length say, 640 mμ, would have to be at a much higher illumination (measured in photons—a unit embodying "cone" visibility by reason of the method of measurement) than a stimulus of wave length less than, say 550 mμ, because the rods are relatively insensitive to light of wave length 640 mμ. On the other hand, if the cones initiate the nerve activity, a stimulus of a given number of photons would yield a certain definite degree of nerve activity regardless of the wave length of that stimulus (retinal region stimulated remaining constant). If this definite degree of nerve activity were just enough to evoke the blue arcs, it is evident that the retinal illumination required would be a constant independent of wave length. We can determine, then, from the shape of the curve of least retinal illumination against wave length (whether it be a constant illumination or higher for long wave lengths) whether, at the lowest illumination evoking them, the cones or the rods initiate the nerve activity responsible for the blue arcs.

II. APPARATUS

The apparatus used was that designed by Priest [21] for another purpose but which is perfectly adapted without change to the present purpose. It provides (1) a 2° circular field which may be more or less strongly illuminated by light of any wave length from 400 mμ to 660 mμ, and (2) an auxiliary photometer by which the brightness of the field may be measured using the flicker method. It should be noted here that the slits (both collimator and ocular) were opened to a width corresponding to 10 mμ, and that filters reducing stray light were used for wave lengths less than 460 mμ and greater than 630 mμ. Also, the diaphragm and ocular slit were so arranged as to constitute an artificial pupil, roughly rectangular, of about 1.5 by 2.0 mm. The auxiliary photometer was calibrated by comparison with a Holophane light meter,[22] but great care was not taken to insure absolute accuracy, since relative accuracy rather than absolute accuracy is important in this experiment. The absolute values reported (fig. 1) may be in error by as much as 20 per cent, but the relative photometric errors are in the neighborhood of 5 per cent.

[21] I. G. Priest, Apparatus for the Determination of Color in Terms of Dominant Wave Length, Purity and Brightness, J. Opt. Soc. Am. and Rev. Sci. Inst., 8, pp. 174–198; 1924.

[22] Adjusted and checked by R. P. Teele, photometric section, Bureau of Standards.

The surrounding field illumination for the right (observing) eye was nearly zero, but for the left eye it was somewhat higher, being due to the blackened surface of the eye shield illuminated by the artificial light of the room. The field on which the arcs appeared was therefore not black, but (since no retinal rivalry appeared) a fairly dark gray. No attempt was made to choose conditions highly

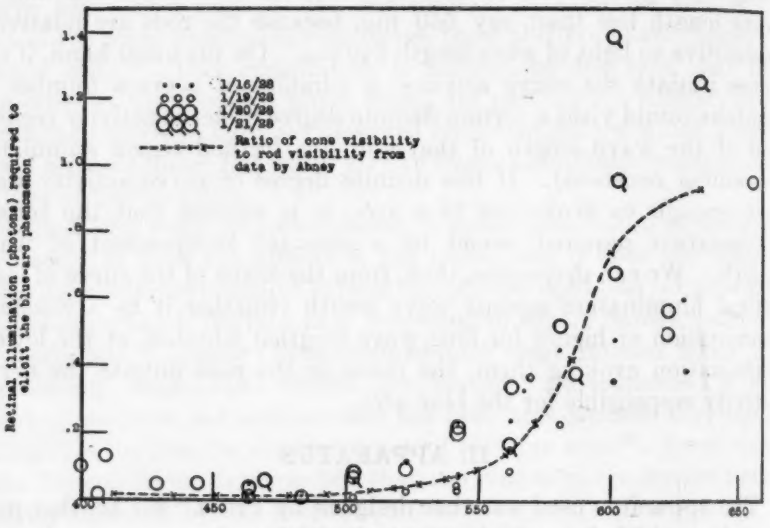

FIG. 1.—*Retinal illumination (photons) required to elicit the blue arc phenomenon as a function of the wave length of the primary light stimulus*

This function agrees well with the ratio of cone visibility to rod visibility from data by Abney

favorable to the production of the blue arcs. They might have been evoked at considerably lower illuminations than those reported if a long narrow vertical slit had been used instead of the circular field, or if they had been projected onto the dark field of the thoroughly dark adapted eyes. The attempt was rather made to approach a uniform and stable state of adaptation.

III. METHOD OF PROCEDURE

The readings were taken on four mornings from 8 to 9 o'clock. The room containing the apparatus was lighted throughout the hour by incandescent lamps. Adaptation was further affected by frequent reading of the illuminated dial of the ammeter attached to the lamp of the auxiliary photometer and by the use of the photometer.

At the start of a determination the wave-length drum was set to the desired reading, a 1 per cent (or 3 per cent or 10 per cent) sector disk was inserted before the collimator slit, and the right eye applied to the eyepiece. The blue arcs were produced by moving the fixation point horizontally away from the stimulus (2° circular field) and were seen to develop from a horizontal band into ever-widening arcs as the distance between the stimulus and fixation point increased. Then, the retinal illumination was decreased (by decreasing the current through the lamp whose ribbon filament was imaged on the collimator slit) to perhaps one-half its value, and the blue arcs again produced by sweeping the fixation point across the right-hand surrounding field. This process was repeated until the blue arcs appeared in only about half the attempts to produce them. The brightness of the field resulting in this condition was then photometered by the flicker method, the 1 per cent sector disk being removed, and the surrounding field illuminated so that its brightness was about 0.5 ml. Since the adjustment of the illumination to the point which just evokes the arcs (that is, a liminal setting) can not be made at all precisely (perhaps a 100 per cent error is not uncommon), only one flicker setting was made. The setting of the wave-length drum was noted on the record sheet. This constituted a single determination.

These determinations were continued without pause until 9 o'clock. No certain evidence of fatigue with respect to the blue arcs, nor of significant change in level of adaptation was found.

The retinal illuminations (I) were calculated from the brightnesses (B) of the surface being viewed according to the formula:

$$I_{\text{(photons)}} = 3.18\, B_{\text{(millilamberts)}}\, A_{\text{(sq. mm)}}$$

or, since the artificial pupil had an area (A) of 3.0 sq. mm:

$$I = 9.54\, B$$

On January 14 the hour was spent in making liminal settings for the sake of practice. Regular observation was commenced on January 16, and all the readings taken thereafter appear plotted in Figure 1, a separate symbol being used for each of the four days.

IV. RESULTS AND DISCUSSION

It is immediately apparent on glancing at Figure 1 that, notwithstanding the low precision (which gives a range of readings at each wave length of about 3 to 1), there is a definite rise [23] with increasing wave length in retinal illumination required to evoke the blue arcs in the author's right eye. Thus, although red light serves best to demonstrate the arcs, still it is true that at the lowest illuminations producing them spectral light of long wave length is definitely less effective than light of short wave length. This situation strongly suggests that the retinal rods initiate the nerve activity responsible for the blue arcs when the retinal illumination is quite low (less than one photon). We shall now proceed to inquire whether the rise in illumination for a stimulus of long wave length is in quantitative agreement with the assumption that the retinal rods initiate the nerve activity responsible for the blue arcs. The derivation of the shape of the curve expected on this assumption may be accomplished in this way:

The liminal setting in each case corresponds to a constant number of impulses per second over the fibers of the optic nerve. The constant number of impulses corresponds to a constant state of activity of the rods (we assume rods, not cones) affected by the primary stimulus. With constant state of adaptation (which has been approximated by the experimental procedure) this constant retinal activity

[23] The points representing the work of each day taken separately all show a very similar rise, but there seems to be a tendency for all points of one day (for example, 1/20/28) to fall above the corresponding points for another day (for example, 1/19/28). This may be due either to (1) a different adaptation level, or (2) a different criterion of appearance or nonappearance of the blue arcs. With respect to (2) it may be remarked that some difficulty was found in adopting a definite and describable criterion for appearance of the arcs. On this account the criterion, although easily remembered throughout a given hour, may not have been the same on the next or any other day. At a liminal illumination a sweep of the fixation point along the horizontal sometimes brought out the moving arcs faintly but with clarity, at other times the suggestion of movement was present without the form of the arcs, and sometimes nothing at all could be detected. There were many gradations between these describable appearances.

It is appropriate at this time to remark that with higher retinal illuminations the arcs are unmistakeably more brilliant than at any of these doubtful stages and take on the pale reddish-blue color that has suggested the name "blue arcs" (at the doubtful stages the arcs appear gray, a fact which is consistent with the "visible radiation" theory). In respect to brilliance variation, my observations substantiate those of Hubbard, who says, "The intensity of the brushes increases with the intensity of the exciting light, * * * " and also those of Ellis (loc. cit., p. 293; 1927) who criticizes Troland's (loc. cit. J. Opt. Soc. Am.) view that the arcs constitute an example of the "all or none law in visual response." While it is true that the observations of Ellis agree with my own, still I do not agree with his criticism of Troland's view because that view is consistent with some variation in brilliance of the arcs even though their brightness (visible radiation theory) or the action current (secondary electric stimulation theory) may be constant. The brilliance should depend, according to that view, somewhat on state of adaptation (and does depend on it, see Amberson, loc. cit., p. 356) and number of nerve fibers activated by the primary stimulus Troland, loc. cit., J. Opt. Soc. Am., p. 168). It seems, on the other hand, reasonable to suppose that Troland himself did not see nearly the variation in brilliance of the arcs that Ellis, Hubbard, or myself have seen, since from measurements he gives (loc. cit., J. Opt. Soc. Am., p. 179) the brilliance of the arcs is only slightly above the threshold. Perhaps Troland might never have been led to cite the blue arcs as an example of the "all or none" law in visual response, if their maximum brilliance for him had been greater. It is my opinion, however, that they should still be thought of as a legitimate example of the "all or none" law even when the observations of Hubbard, Ellis, and myself be taken into account. If Troland's view is to be rejected, evidence must be found by Troland's own technique showing that the brilliance of the blue arcs for other observers is actually as variable as the qualitative observations (just cited) indicate.

is due to the constancy of the product, $E_\lambda(V_r)_\lambda$, where E_λ is the energy (that is, ergs per second per unit visual angle) of the light stimulus of wave length λ, and $(V_r)_\lambda$ is the rod visibility for that wave length. We have the relation, then, that the shape of the curve of retinal illumination (I_λ) must be such that

$$E_\lambda(V_r)_\lambda = \text{a constant}$$

But we measure $E\lambda$ by measuring the illumination corresponding to a large multiple (most often here, 100) of it, thus:

$$E_\lambda = KI_\lambda/(V_c)_\lambda$$

where $(V_c)_\lambda$ is the cone visibility of light of wave length λ. (K is the constant which determines the units in which E_λ is expressed.) We believe that only the cones are effective in this photometric measurement by reason of the experimental conditions adopted (2° field of high brightness, bright surrounding field). Solving for I_λ from these two relations, we obtain

$$I_\lambda = (V_c)_\lambda/(V_r)_\lambda \text{ times a constant}$$

On Figure 1 is also shown, therefore, this ratio, $(V_c)(/V_r)_\lambda$ evaluated from data by Abney.[24] It is seen that this ratio (multiplied by a constant arbitrarily selected to secure the best agreement) varies with wave length in such a way as to agree substantially with the measurements taken of the least retinal illumination (I_λ) required to evoke the blue arcs.[25] There are two outstanding departures

[24] Abney, Researches in Colour Vision, pp. 94, 98; London: Longmans-Green; 1913. Column IV, Table IV, p. 94; Table VI, p. 98. This data of Abney is taken because none of the more recent observers apparently used quite the field size which would make their results applicable to this case. It seems clear from Amberson's results (loc. cit., p. 359) that the blue arcs result from a stimulation of the outer zone of the macular region (that is, the macula lutea minus the central rod-free area). Abney's data refer specifically to the macula lutea (yellow spot). To my knowledge, no other investigator gives this specification. There are apparently large individual variations in the size of the yellow spot; Parsons (Introduction to the Study of Colour Vision, Cambridge: University Press, p. 13; 1924) says that the macula may vary from 4° to 12° in different individuals. In Amberson's case, a 6° circular field includes all retinal elements capable of giving rise to the blue arcs. Visibility data taken with a 6° field would, however, be as reliable as that taken (as Abney's data was) specifically for the observer's yellow spot only if the yellow spot of the observer covered the entire 6° field. Otherwise errors would be introduced by absence of information concerning macular pigmentation. Laurens (Am. J. of Physiol., **67**, p. 354; 1924) gives data referring to a 2° field, which is probably too small. This data checks Abney closely, however, giving, as expected, a ratio curve (V_c/V_r) which does not rise quite so steeply as that shown in Figure 1.

[25] It is convenient to note at this point that the results of Troland (loc. cit., Psych. Bull.) on the least retinal illumination required to evoke the blue arcs are not in complete agreement with those referring to the present author's right eye. Just how serious the discrepancies are can not be determined because the account of Troland's results is purely qualitative and is contained in a brief abstract. He says "Measurements of the threshold of the phenomenon with respect to intensity indicate that this is in the neighborhood of one photon, and that there is a distinct minimum in the middle of the spectrum, the curve for the effect corresponding roughly with a reciprocal of the visibility curve." The present results indicate that the threshold is in the neighborhood of one one-hundredth photon (for some wave lengths). There is a minimum (though not distinct) in the middle of the spectrum, and the curve does not (see fig. 1) resemble, even roughly, a reciprocal of the visibility curve (it scarcely rises at all toward short wave lengths). It is possible that these differences are to be expected from the relatively low brilliance (see footnote 23, p. 348) of the blue arcs in Troland's case. Such a brilliance might reasonably necessitate the intensity threshold of one photon which Troland found. This high threshold should account for the rise of the curve toward short wave lengths. (See footnote 26, p. 350.)

from perfect agreement: (1) The rise of the ratio between 550 mμ and 600 mμ is steeper than that of the average I_λ; and (2) the ratio is smaller between 400 mμ and 500 mμ than the average I_λ. Although the agreement is as good as, perhaps better than, can be expected in view of the fact that two different observers are involved, perhaps a part of the failure of the I_λ curve to rise as steeply as the ratio curve may be ascribed to the fact that the slit widths of the spectrometer were quite large (10 mμ). The failure of the I_λ curve to fall to the low values between 400 and 500 mμ reached by the ratio curve may be ascribed to the fact that the primary stimulus, though quite weak (about 0.04 photons), introduced enough scattered light into the field on which the arcs were projected to interfere seriously with their observation.[26] This scattering became more and more troublesome as the wave length of the primary stimulus was decreased. Similar difficulties have been noted by Hubbard,[27] Troland,[28] and Ellis.[29]

It may be concluded, in my opinion, from the work just described, that at low retinal illuminations the blue arcs are evoked from nerve activity initiated by the retinal rods. This conclusion is in agreement with Amberson's results on retinal regions giving rise to the blue arcs. Although other work (summarized in the introduction)[30] suggests that the cones may also initiate the nerve activity responsible for the blue arcs, it is my opinion that this has not yet been established as a fact.[31]

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[26] We should expect Troland's curve resulting from a much higher illumination (about 1 photon) to depart considerably more from the ratio curve on this account. Such a departure is in agreement with the actual curve he found. (See footnote 25, p. 349.)

[27] Hubbard, loc. cit., p. 198.

[28] Troland, loc. cit., J. Opt. Soc. Am., p. 176.

[29] Ellis, loc. cit., p. 292; 1927.

[30] In agreement with this work, I find that a red (630 to 640 mμ) primary stimulus is best in my case also for demonstration of the blue arcs, but it is only slightly better than a green or yellow stimulus. This I ascribe, not to participation of the cones, but to the resulting comparative freedom from scattered light of the field on which the arcs must be projected. This explanation is also given by Ellis (loc. cit., p. 293; 1927).

[31] My view is that probably all nerve fiber, forming rod pathways or cone pathways, retinal or central, active or inactive, is emitting physical light. It seems likely that the rate of emission increases as the degree of activity of the fiber increases (though it is possible that this view conflicts with Troland's undisproved contention of essentially constant brilliance of the blue arcs). It seems significant in this connection to note that the only two cases (blue arcs and Purkinje phase of the periodic afterimage), which demand the postulation of "visible radiation," arise in association with, and only in association with, intense activity of the rod pathways. My view is that the radiation emitted under other conditions (for example, from cone pathways activated by primary stimuli usual for demonstration of the blue arcs—note Amberson's failure to obtain the arcs from purely foveal stimulation—or from rod pathways after a few seconds duration of the stimulus—note transitory character of the blue arcs which has troubled the proponents of the secondary electric stimulation theory since its inception) is too weak to be detected even by the wonderfully sensitive retinal layer only a fraction of a millimeter away. We should not expect the retinal cones to initiate the nerve impulse which causes visible blue arcs because the light scattered from the primary image strong enough to stimulate the cones suitably would be many times as intense as the light emitted by the active fibers of the cone pathways. Furthermore, we should not expect the rods to retain a sufficiently high sensitivity to initiate for more than a few seconds the nerve activity which results in vivid blue arcs. The sensitive substance bleaches out rapidly; and during this rapid bleaching out, and only during this rapid bleaching out, do vivid blue arcs (or vivid Purkinje phases) appear.

It is also true, in my opinion, that the hypothesis of visible radiation from active nerve fiber proposed by Druault and Ladd-Franklin and used by me [32] to account for certain properties of the Purkinje phase of the periodic afterimage is somewhat strengthened by this work, because this work indicates that the nerve activity responsible for the blue arcs sometines (perhaps always) arises from the same origin (retinal rods) as that responsible for the Purkinje phase of the periodic afterimage following brief stimulation of the retina [33] by light. The two phenomena are linked, therefore, by one more common property. Since cogent arguments (Ladd-Franklin) indicate that the blue arcs are due to visible radiation from active nerve fiber, it is, in my opinion, reasonable to suppose that the Purkinje phase is due, at least in part, to the same cause.

WASHINGTON, November, 1928.

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[32] Judd, loc. cit., p. 527. The term used here as a substitute for "visible radiation" is "bioluminescence."

[33] In further confirmation of this linkage of the Purkinje phase with the blue arcs, may be mentioned the fact that W. T. M. Forbes obtains them both only with abnormally high retinal illuminations. (See for the Purkinje phase: Judd, loc. cit., p. 521, fig. 2, observer W. T. M. F. requires 56 photons, which is about one hundred times that required by some other observers.) He requires about 10 photons (compare Judd, present work, 0.01 photon) for evoking the blue arcs. This evidence was pointed out by Doctor Forbes himself, who says (letter of November 14, 1928), "You have, as confirmatory, the fact that in my case the blue arcs did not appear with weak stimuli, * * *" and (as just cited) neither did the Purkinje phase.

THE SERVICE OF REFRACTORY BLOCKS IN A SMALL EXPERIMENTAL GLASS TANK

By W. L. Pendergast and Herbert Insley[1]

ABSTRACT

Tests to determine the relative resistance of various types of refractories to the action of flowing molten glass were made in a small laboratory glass-melting furnace similar in shape and in operation to commercial scale continuous glass tanks. The results of tests made in nine runs of the furnace, each run continuing for approximately 30 days, are given. Clay tank block of commercial manufacture as well as blocks made of unusual compositions and by unusual processes were tested.

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I. INTRODUCTION

During the past few years there has been a marked tendency in the glass industry to increase the temperature for melting glass. This, naturally, has resulted in a more rapid disintegration of the refractory blocks used in the walls and other parts of continuous tanks. Moreover, refractory blocks from different manufacturers have shown

[1] Acknowledgments are due R. F. Geller for his part in this investigation. The program was outlined by him and the entire investigation up to and including the run of the ninth tank was under his direct supervision.

widely different resistance to glass attack, and even blocks from the same manufacturer made apparently of the same materials and with the same processes have at times varied greatly in service.

While some theories have been advanced to account for the difference in resistance of different blocks, apparently little experimental work has been done to evaluate and correlate the factors that determine the degree of resistance of tank block to glass attack. The Bureau of Standards in 1924, therefore, inaugurated a laboratory investigation on commercial tank block with the hope that it would throw some light on the subject. For this purpose experimental, gas-fired, continuous glass tanks were constructed so that the tank blocks in the sides could be easily replaced. Nine melts were made between September, 1924, and October, 1927, using refractories prepared in the laboratory as well as blocks furnished by various manufacturers.

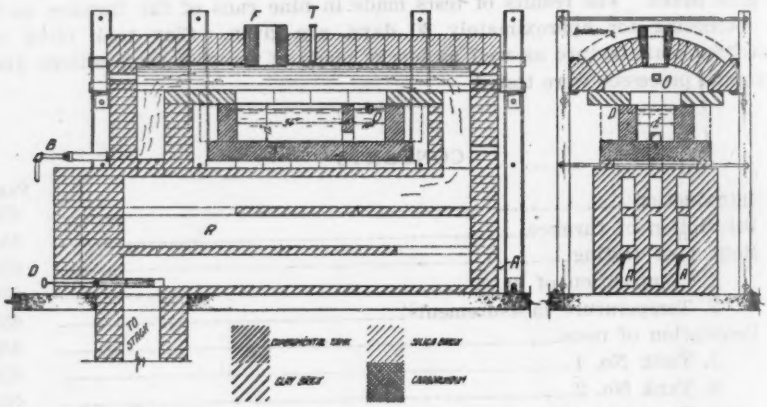

FIG. 1.—*Drawing of furnace showing position of tank and batch-feeding tube and the direction of gas flow*

Glass was melted in each of the nine tanks, a test run continuing for approximately 30 days.

II. DESCRIPTION OF FURNACE

In its final form the furnace was a modified down-draft kiln, the gases burning while they passed horizontally over the tank. The furnace operated quite satisfactorily, considering that the fuel used was a carburetted water gas supplied for domestic use, averaging about 600 B. t. u. per cubic foot. Two burners with one-half-inch orifices were sufficient to maintain the required temperature. The tank itself was 12 inches high, 12 inches wide, and 4 feet long, the glass level being maintained about 2 inches from the top of the tank B. Batch was fed in at *F* (fig. 1); the molten glass passed through the opening in the bridge wall and was drawn off at *D*. The crown was of silica brick with the exception of the carborundum block which

FIG. 2

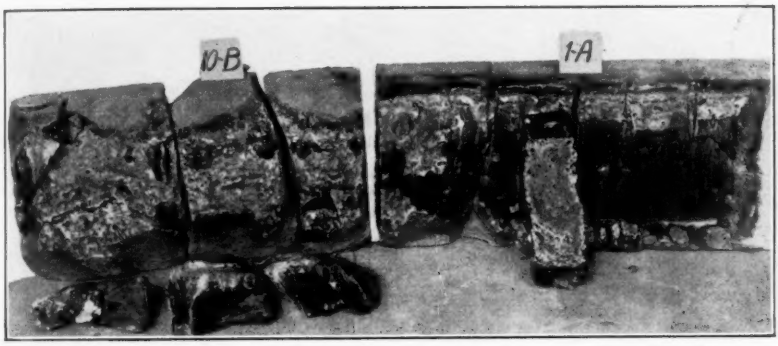

FIG. 3

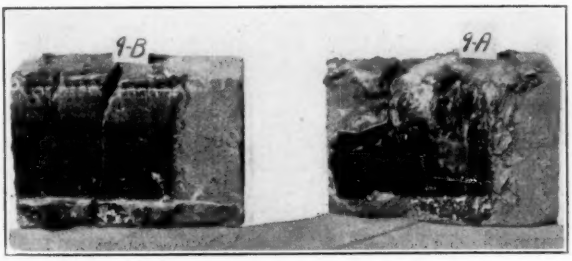

FIG. 4

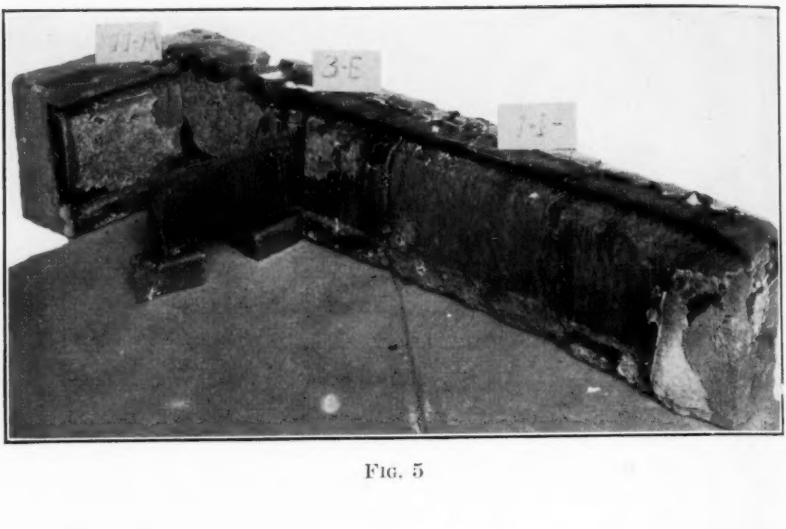

FIG. 5

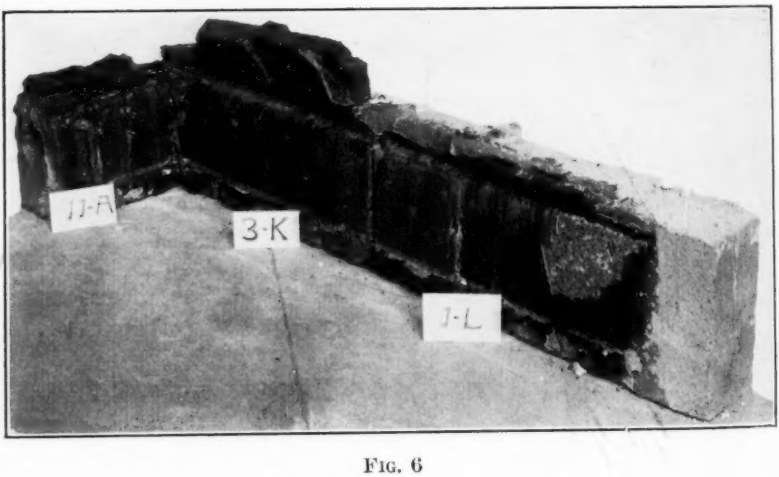

FIG. 6

contained the batch-feeding hole *F* (fig. 1). The bottom blocks and tuck stones were made of a modified glass-pot body developed at the Bureau of Standards and composed of 50 per cent fire-brick grog burned to cone 16 and 50 per cent of unburned material. The unburned material was composed largely of Tennessee and Kentucky ball clays and North Carolina kaolin with minor amounts of Georgia and Delaware kaolins and feldspar.

III. METHOD OF TESTING

Batch fills of 12½ pounds each were made every 15 minutes during 8 consecutive hours. Results showed that the rate of glass movement under these conditions was sufficient to give marked corrosion with most refractory blocks at the end of 30 days' melting time.

1. COMPOSITION OF BATCH

The batch used was composed of 1,000 pounds of sand, 700 pounds of soda ash, 200 pounds of limestone, and 2 pounds of sodium nitrate. One part of cullet was mixed with three parts of batch.

The calculated chemical composition of the batch, based upon the proportions used and chemical analyses made of the soda ash and limestone, is SiO_2 66.3 per cent, Na_2O 26.8, CaO 4.0, and MgO 2.9. This batch is considerably higher in soda than the average soda-lime bottle glass batch and therefore more corrosive.

2. TEMPERATURE MEASUREMENTS

The temperatures during the melting period were read with an optical pyrometer which was sighted on the center of the arch. In one run four platinum, platinum-rhodium thermocouples were inserted through small holes in the side-wall blocks. Three of the couples were inserted midway of the length of the furnace, one at the surface of the glass, one near the bottom of the tank, and one halfway between. The fourth couple was 10 inches nearer the end wall of the melting chamber than the other three and at the bottom of the tank. A difference of about 50° between couples at the bottom and top of the glass in the same vertical line was observed. The couple at the surface of the glass gave a temperature about 50° lower than the optical when the optical read 1,550° and about 40° lower when the optical read 1,530°.

IV. DESCRIPTION OF TESTS

1. TANK NO. 1

The side walls of the first tank were built of six blocks furnished by three manufacturers. The blocks marked 1–A (fig. 3) and 1–B (fig. 2) were from the same manufacturer and were alike in composition and treatment except that 1–B was reburned to cone 15 at the Bureau of Standards. All the blocks were 6 inches thick.

Since this was a first run, various unforeseen troubles arose which necessitated shutting down the furnace three times. Consequently, the time during which batch was melted was only 13 days. The average temperature during the melting period was 1,420°, and 3,800 pounds of batch were melted. The severity of service in this tank was considerably less than in any other tank in the series. Nevertheless, the blocks showed fairly severe corrosion. Figures 2 and 3 are photographs of the side-wall blocks arranged after dismantling the tank in the relative position which they occupied during the run. The bridge wall is toward the left in Figure 2 and toward the right in Figure 3. The end wall blocks are shown in Figure 4, the melting chamber end wall on the right and the refining chamber end wall on the left. All of the blocks showed serious spalling at the upper inside edges, probably because the furnace was shut down several times during the first three days of the test.

2. TANK NO. 2

The side walls of tank 2 were built of six commercial blocks, all 6 inches thick, furnished by three manufacturers. Block 1–I is the same as 1–L, except that the former was reburned to cone 15. (Figs. 5 and 6.) Batch was melted in this tank for 34 days at an average temperature of about 1,450° C. Nine thousand pounds of batch were used. Although this average temperature was slightly higher (25°) than that of tank 9, the melting period was 10 per cent shorter and the amount of batch used 25 per cent less. (Table 1.) As affecting the amount of corrosion on tank walls, therefore, service conditions in tank 2 were probably slightly less severe than in tank 9. Figure 5 is a photograph of one side wall, a portion of the bridge, and the refining end wall, and Figure 6 shows the other side wall and the melting end wall. The bridge-wall block, which was a commercial refractory, was partially destroyed, but all the side-wall blocks were quite free from pits and corrugation and showed little evidence of corrosion except at the glass line. Even at the glass line the depth of corrosion was not great as compared with that in most of the other tanks in the series. The commercial block reburned to cone 15 showed 9.2 per cent absorption as compared with 13.0 per cent absorp-

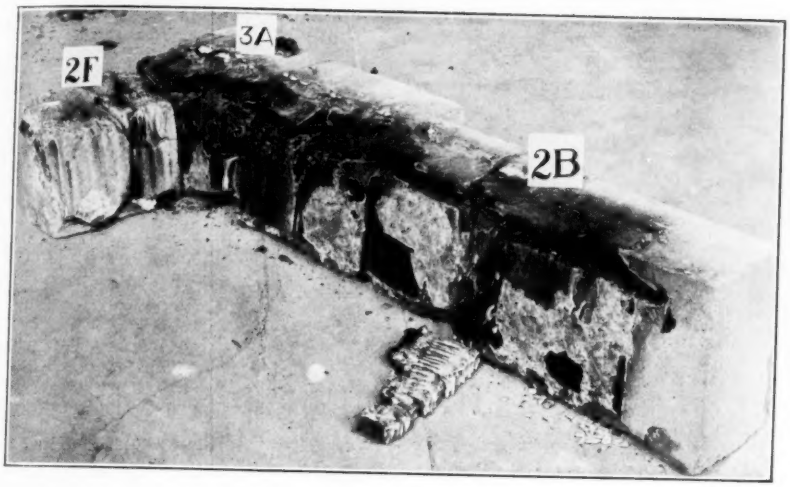

FIG. 7

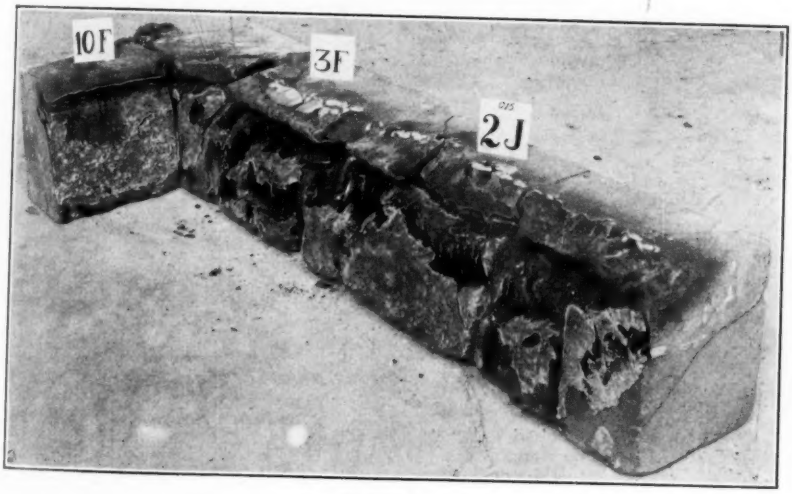

FIG. 8

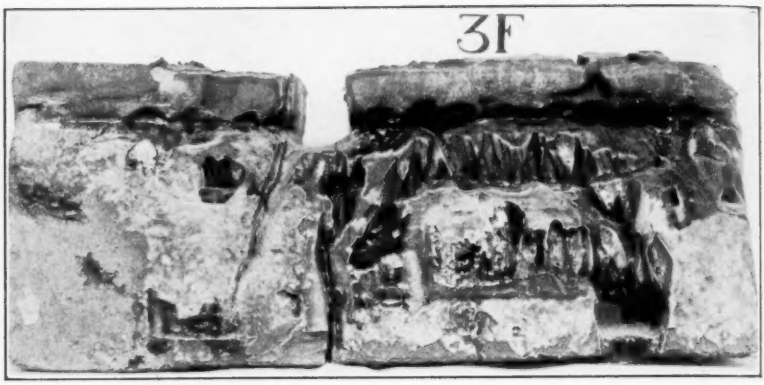

FIG. 9

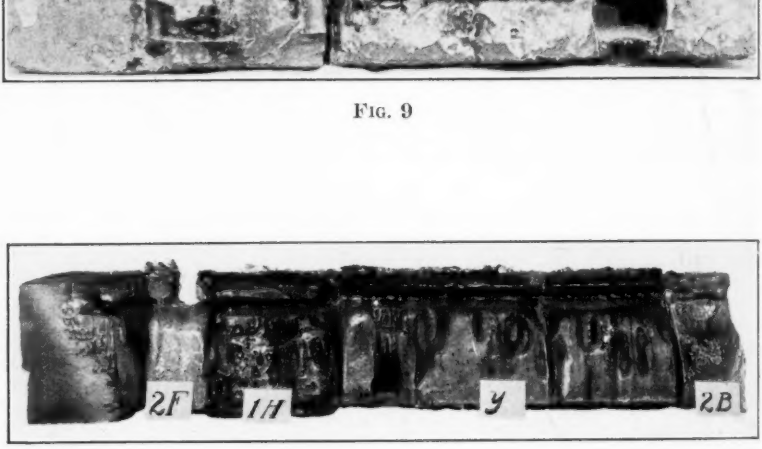

FIG. 10

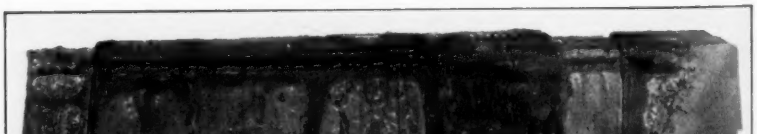

FIG. 11

tion for the block of the same manufacture not reburned. The reburned block also showed a slightly greater resistance to glass attack.

3. TANK NO. 3

The six blocks making up the side walls of tank 3 were from three manufacturers, and the bridge wall also was a piece of a commercial block. During a melting period of 26 days the tank was operated at an average temperature of 1,525° C., and approximately 9,000 pounds of batch were used. Although the average operating temperature was about as high as for any tank in the series, the melting period was unusually short. Consequently, the severity of service was less than for tanks 4, 5, and 6, and may be considered as about equal to tank 7. Figure 7, a photograph of one side wall, the melting-chamber end wall, and a detached piece of the bridge, shows the marked effects of glass attack on the end wall and the blocks in the melting end of the tank. Figure 8 is a photograph of the other side of the tank with the refining-chamber end wall. The bridge was eaten through and broken away from the side walls, and the indentation at the glass line was greater than 2 inches on all the blocks in the melting end of the tank and reached a maximum of 3¾ inches on block 2J. (Fig. 8.) Block 2J showed more attack than any other block in the tank. This was in large part due to the presence of vertical and horizontal cracks or laminations which provided starting places.

Corrosion upward from horizontal cracks, so characteristic of the action in many commercial tanks,[2] is well exemplified in blocks 3F (fig. 9), 3A (fig. 7), and 2F (fig. 7). Block 2F was also worn back greatly above the glass line. It should be noted that this block contained more silica (73 per cent) than any other wall block used in this series of experiments.

One sample of each of the following materials was dropped into the melting chamber of tank 3 and left there until the end of the run:

A. Fused quartz disk (13 ounces).

B. Cylinder of calcined alumina and kaolin (approximately 50 per cent SiO_2, 50 per cent Al_2O_3) burned to 1,400° in three hours (20 ounces).

C. Fire-clay brick (38 ounces).

D. Sandstone block (70 ounces).

E. Fused alumina block (46 ounces).

F. High alumina (80 to 85 per cent Al_2O_3) block (55 ounces).

[2] Ross, D. W., Wearing Away of Tank Blocks, J. Am. Ceram. Soc., 9, pp. 641–654; 1926.

All the specimens had dissolved or disintegrated except the fused alumina block, which was reduced to about one-half the original size and the high alumina block which was reduced to one-quarter the original size.

4. TANK NO. 4

Tank 4 was built of commercial blocks, all 8 inches thick. It was run for a melting period of 36 days at an average temperature of 1,525° C., and 13,000 pounds of batch were used. This tank undoubtedly had the severest service of any in the series. All the blocks were greatly worn both at and below the glass line. Figure 10 shows one side wall and a part of the refining end wall, Figure 11 the other side wall and a part of the melting end wall. In the melting chamber the average depth of erosion at the glass line was 5 inches and below the glass line more than 1 inch. In blocks Y and 2D irregular vertical channels and horizontal benches were formed which began at cracks. Although blocks marked "2B" were very badly worn, they showed no evidence of cracks or laminations. The difference in depth of corrosion on these blocks and the adjoining ones is well shown in Figure 12. The bridge wall although 11 inches thick was almost entirely eaten away below the glass line. (Fig. 13.)

5. TANK NO. 5

Tank 5 was built of six commercial blocks and three special blocks. Of the latter one (GP) was made of a glass pot body using firebrick grog, and the other two (marked "BS30") were made from batch furnished by a block manufacturer which was made up and fired to cone 15 at the Bureau of Standards. The tank was operated during a period of 35 days at an average temperature of 1,525° C., and 11,000 pounds of batch were melted. The conditions in this tank were only slightly less severe than in tank 4.

The blocks in the melting chamber (on the right in fig. 14 and on the left in fig. 15) showed marked effects of glass action. Block 8A is unusual in that it shows numerous, repeated, vertical flutings or corrugations. The deeper channels due to pronounced vertical cracks or laminations can also be observed. Block GP was worn to a depth of 5 inches at the glass line. Below the glass line the surface in contact with the glass was honeycombed with pits. (Figs. 15 and 16.) In places these pits extended to within 2 inches of the cool surface. The pitting may be ascribed to a combination of rather high porosity and to easy solubility in the glass. Although the blocks contain only about 56 per cent of silica, the percentage of fluxes present is rather high, about 3 per cent. One of the blocks made at the Bureau of Standards from a manufacturer's batch was used in

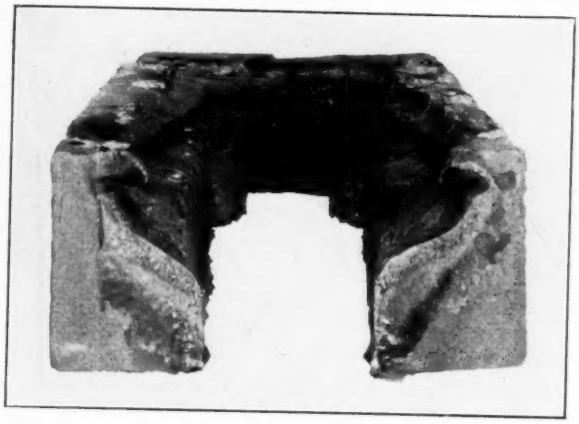

FIG. 12

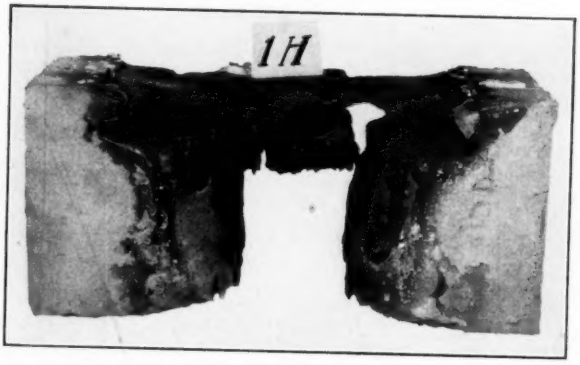

FIG. 13

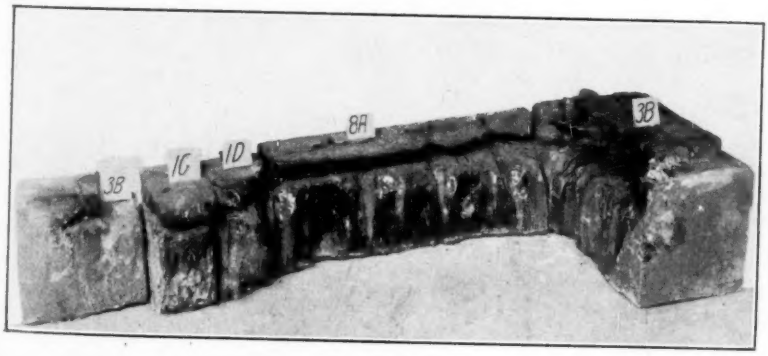

FIG. 14

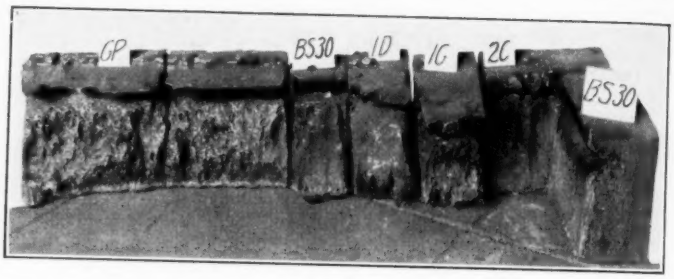

FIG. 15

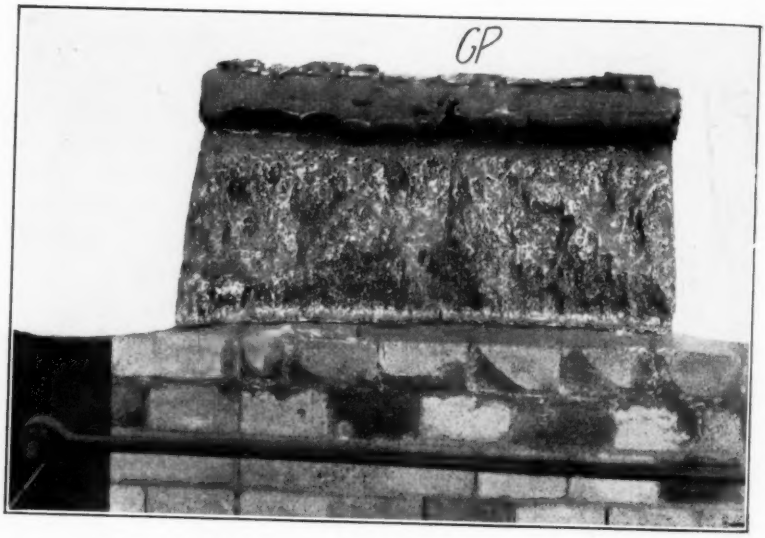

FIG. 16

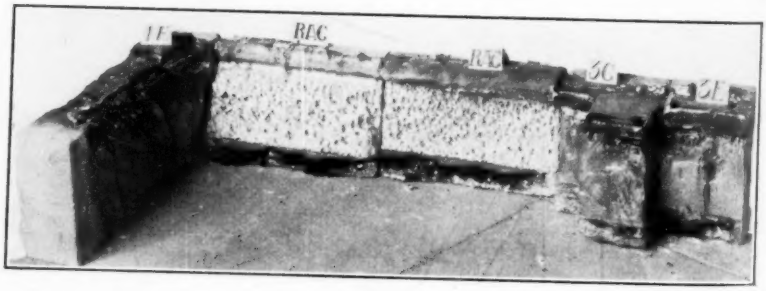

FIG. 17

the melting chamber. (BS30 in fig. 15.) It withstood corrosion very well, but its position next to the bridge wall was particularly favorable.

6. TANK NO. 6

The walls and bridge of tank 6 were built of 5 commercial and 5 experimental blocks. All the blocks were 6 inches thick except the bridge block, which was 10 inches. The tank was operated for 36 days at an average temperature of 1,500° C., and 12,000 pounds of batch were melted. While the average temperature was 25° lower than in tank 5, the amount of batch used was slightly greater. Of particular interest were the tests on the experimental blocks. The blocks marked RAC (fig. 17) were composed of artificial corundum (made by electric furnace fusion) of 14 mesh or finer. The alumina grains were bonded with 10 per cent clay and burned. As Figure 17 shows, these blocks were badly honeycombed and eaten away. The depth of indentation at the glass line was about 3 inches. The blocks marked RSC (fig. 18) were composed of crystalline mullite (made by electric furnace fusion) of 14 mesh or finer. The mullite grains were bonded with kaolin and alumina in the proportions to give mullite and fired. The mullite blocks were also badly corroded and honeycombed, although the pits were much smaller than in the alumina blocks. (Fig. 19.)

An experimental block 3 inches thick composed largely of spinel ($MgO.Al_2O_3$) was placed in the tank as a part of the bridge wall. It formed the portion of the bridge wall in the melting chamber and was backed by a clay block 7 inches thick. The only remaining fragment of this block is marked MA. (Fig. 18.) It seems probable from this evidence that spinel is readily attacked by molten soda-lime glass. Although the clay portion of the bridge (3C, fig. 18) was eaten through, it withstood glass attack far better than the spinel.

7. TANK NO. 7

The walls of the melting chamber of tank 7 were built of two alumina blocks, two mullite blocks, and one block (forming the end wall) of a commercial batch burned to cone 15 at the Bureau of Standards. The bridge wall was made of two blocks, back to back—a Georgia kaolin block burned to cone 15 at the Bureau of Standards facing the melting chamber and a block of commercial batch burned to cone 15 at the bureau facing the refining chamber. The side walls of the refining chamber were two commercial blocks of the same brand, and the end block was of Georgia kaolin burned at the Bureau of Standards.

The tank was operated for 37 days at an average temperature of 1,450° C., and 12,000 pounds of batch were melted. Due to the lower

temperature, service conditions were somewhat less severe than in tank 6.

The blocks marked RAF (fig. 20) were of the same composition (90 per cent artificial corundum, 10 per cent clay) as the blocks RAC in tank 6, but the alumina was much finer grained. Of this pair the block on the right was originally 6 inches thick from the bottom to a horizontal line about 4 inches from the top. Above the line the inside face was beveled off, so that the glass surface made an oblique angle with the face of the block. The block on the left was 4 inches thick below the horizontal line shown in the photograph and 6 inches above. The latter block was made in this way to furnish a ready-made horizontal downward facing surface where the characteristic "upward eating" could take place if the block were susceptible to it. Figure 20 shows some evidence of this action. The fine-grained alumina blocks offered much greater resistance to glass action than did the coarser-grained blocks. (Figs. 17 and 19.) The alumina blocks in tank 7 were eaten back about 1 inch at the glass line. No pitting was visible on the surface exposed to glass action.

The mullite blocks (RSF in fig. 21) were the same as the mullite blocks in tank 6 except for increased fineness of grain. Here, again, the finer-grained blocks showed a marked improvement in resistance to glass action. The left-hand block in Figure 21 was corroded to a depth of 1 inch at the glass line, the right-hand block to a depth of 2 inches. In general, there was little wearing away below the glass line, although in the left-hand block there are two cracks along which marked corrosion had taken place. These cracks may have formed during the heating period in the tank before glass melting began. The Georgia kaolin blocks forming the end wall in the refining chamber and a part of the bridge wall are seen in Figure 21 (GA–1 and GA–2). The end wall was corroded at the glass line to a depth of 2½ inches and was very badly pitted below the glass line. The portion of the bridge wall composed of the kaolin block was eaten through from bottom to top and was also badly pitted. Needless to say, such a test does not give a fair idea of the solubility of burned kaolin in molten glass. The structure was necessarily very open, and apparently disintegration of the block was caused primarily by entrance of molten glass into the pores.

8. TANK NO. 8

All of the blocks in the melting chamber of tank 8 were experimental with the exception of the end wall. The tank was operated for 27 days at an average temperature of 1,450° C., and approximately 11,000 pounds of batch were melted. Although the average melting temperature was 25° higher in tank 8 than in tank 9, the duration of run and the amount of batch melted were considerably

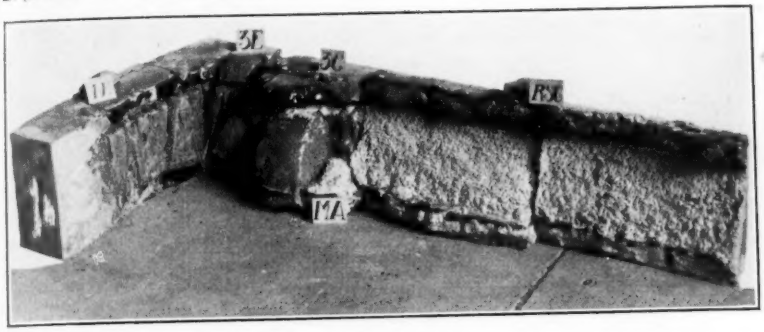

FIG. 18

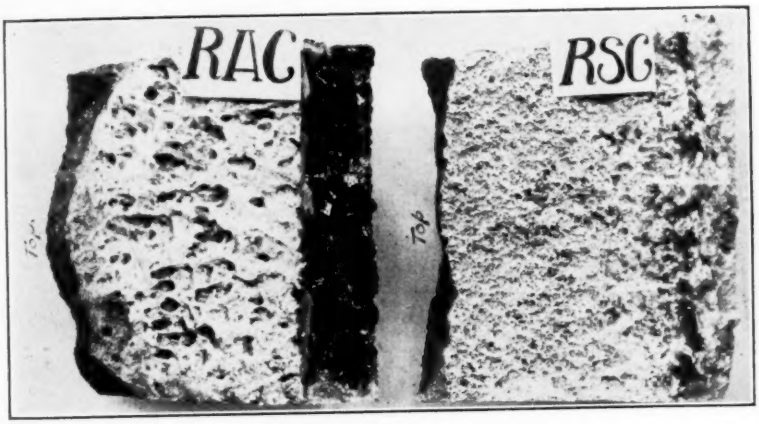

FIG. 19

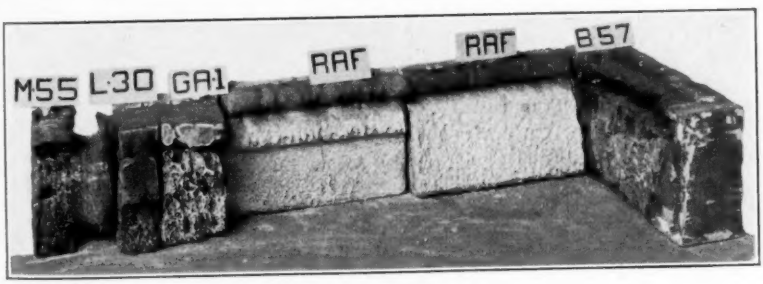

FIG. 20

FIG. 21

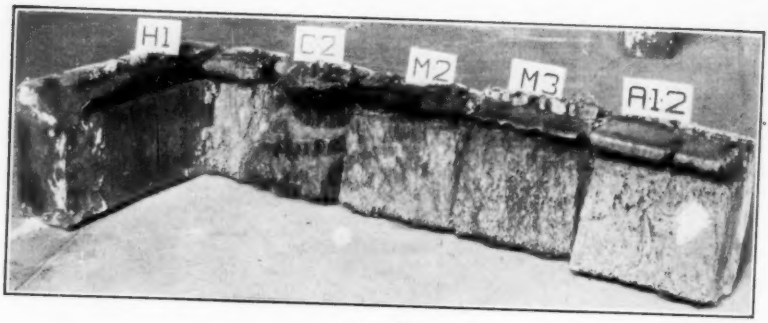

FIG. 22

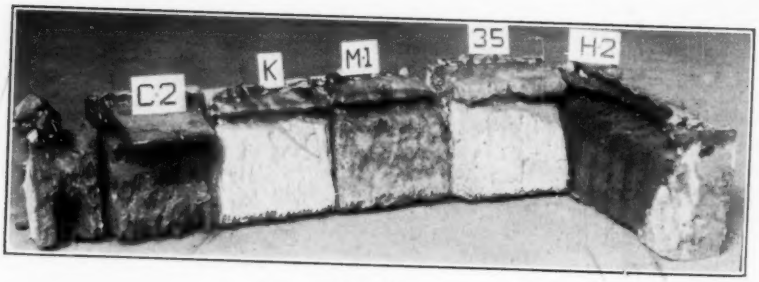

FIG. 23

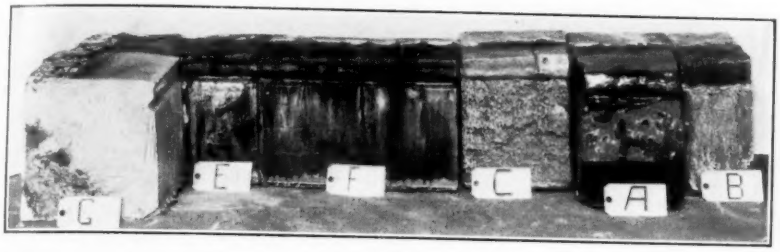

FIG. 24

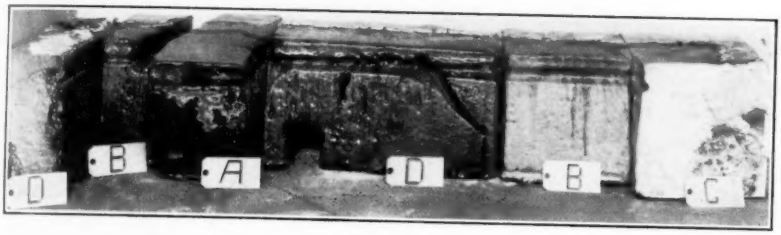

FIG. 25

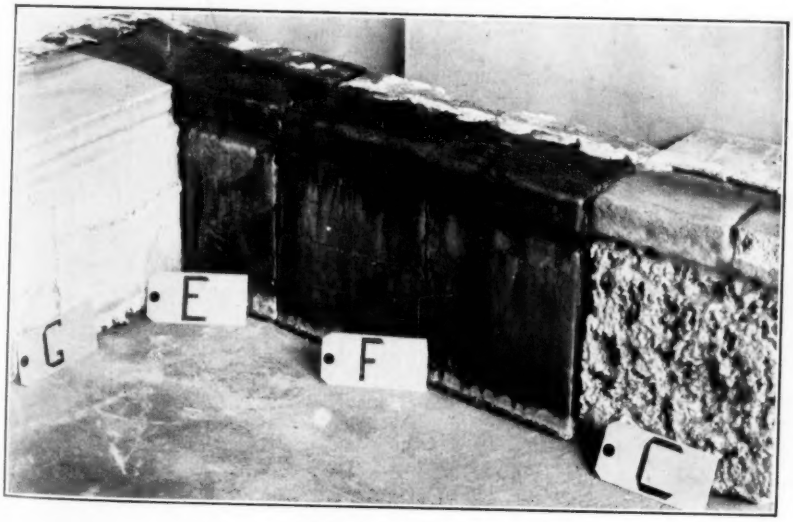

FIG. 26

less than in the latter, and the severity of service can be considered approximately the same in the two tanks.

The blocks in the side walls of the melting chamber (figs. 22 and 23) resisted glass action unusually well, probably in part because the operating conditions were not as severe as in some of the runs. The commercial block in the end wall of the melting chamber (H2), however, showed as much wear as end blocks in runs where operating conditions were more severe.

Blocks M–2 (fig. 22) and M–1 (fig. 23) were dry-pressed blocks made wholly of Missouri flint clay. The grog, composing 45 per cent of the block, was burned to cone 14 at a plant manufacturing tank block, shipped to the bureau, where the raw clay was added, dry pressed at 1,500 lbs./in.^{2}, and burned to cone 16. These blocks were worn 1½ inches at the glass line and were in comparatively good condition at the end of the run. Block M–3 (fig. 22) was a handmade diaspore block, burned to cone 16. It was worn to a depth of 1½ inches at the glass line and apparently was similar to M–2 in resistance to glass action. Block A–1–2 (fig. 22) was an experimental hand-rammed block made of calcined cyanite. Although it showed fair resistance to glass action and was worn only 1½ inches at the glass line, it was badly pitted and contained one long curved crack along which marked corrosion took place. Block 35 (fig. 23) was made of the same material as block A–1–2 but was dry-pressed to 3,500 lbs./in.^{2} instead of hand rammed. As the photograph indicates, this block withstood glass action much better than A–1–2, the pits were few and small, and there were no cracks. Block K was made of the glass pot batch used in the bottom blocks and tuck stones in all the experimental tanks, but was dry pressed to 850 lbs./in.^{2} instead of being hand rammed. The block was in good condition after the run except for a large crevice probably formed during the burning of the block or the heating up of the tank.

9. TANK NO. 9

All the blocks in the walls of tank 9 are of the so-called "special refractory" type, with the exception of the bridge, which was built of a commercial clay tank block, and block D, which is a commercial clay block fabricated by an unusual process.

This tank was operated at an average temperature of 1,425° for 38 days, during which time 12,000 pounds of batch were melted. While conditions in this tank were less severe than in tanks 4, 5, 6, and 7, they were probably approximately the same as in tanks 2 and 8. (Table 1.) Tank 2 was operated at an average temperature 25° higher than tank 9, but considerably less batch was melted. In tank 8 the average temperature was also 25° higher than in tank 9, but the duration of the run was much shorter.

The effect on the wall blocks is seen in Figures 24, 25, and 26. Block A, the bridge wall, is a commercial clay block. It shows severe corrosion, but considering that the bridge wall in many runs was almost wholly eaten away, it resisted glass action remarkably well.

Block C (figs. 24 and 26) was a special refractory. Petrographic examination showed that it was composed largely of very minute crystals of mullite in glass with a little granular corundum. Apparently a large part of the mullite and glass had been formed by the dissociation of cyanite, since large aggregates of minute needles of mullite and glass contained remnants of undissolved cyanite grains at their centers. This block was badly pitted after service and showed the least resistance to corrosion of any block in the tank. Disintegration probably resulted more from porous structure or from lack of homogeneity than from chemical composition. Blocks E and F (figs. 24 and 26) were from the same manufacturer and were made, it is understood, of an electrically fused mixture containing alumina and silica in the proper proportions to form mullite.

After use in the furnace the blocks were broken in half and specimens chipped from several places on the fractured faces. Petrographic examinations of these chips gave the following results: Block E was found to be composed of mullite ($3Al_2O_3.2SiO_2$), corundum (Al_2O_3), glass and opaque material. In all the chips examined mullite was the most abundant constituent, although the relative amount present varied from place to place in the block. Corundum varied from 10 to 30 per cent. Glass in small amounts was observed in channels between the mullite crystals. The opaque material occurred as lenticular masses and dendritic growths included in both mullite and glass. Chips from block F were composed largely of corundum with small amounts of glass, mullite, and an unidentified compound with very high index of refraction and high double refraction. Corundum occurred in large, well-formed crystals and was evidently the first compound to crystallize. The mullite crystals, although very small, were well developed and were inclosed in glass. In all probability crystallization of the mullite took place after the corundum.

These two blocks showed greater resistance to glass attack than any of the other blocks in this series of tests. The indentation at the glass line was only one-half to five-eighths of an inch with a maximum corrosion at the center of the block of about one-fourth inch. Block E cracked some time after installation. The surface also shows some checking. Block F was partially cracked when received, and the cracks continued through the block during test. Glass attack at the cracks in these blocks was not appreciably more than at any other part of the surface of the block below the glass line. (Fig. 26.)

Block G used as the end wall of the melting chamber was a special refractory. Petrographic examination showed that it was composed of fairly coarse grains of corundum and mullite with interstitial glass. The interstitial glass often contained well-developed needles of mullite. The structure suggests that the block is composed of mullite and corundum formed by electrical fusion afterwards bonded with an aluminum silicate (perhaps clay) and fired to a rather high temperature. Although the block was in a position in the furnace where corrosive action of the melt was pronounced, it showed excellent resistance to such action. There was an indentation at the glass line of about an inch, while the center of the exposed face was corroded only about one-half inch. Four cracks developed in the same block some time after installation, but glass attack along these cracks was not excessive.

Block B was a special refractory composed, according to petrographic examination, of corundum, andalusite and quartz in fairly coarse grains, corundum and andalusite being the most abundant constituents. The edges of the andalusite grains were converted to a mixture of mullite and glass. This block also withstood glass attack exceptionally well. A few very small pits were found in the face of the block, and the indentation at the glass line was only about an inch.

Block D is a clay block which, it is understood, received a somewhat unusual treatment before burning. This block compared favorably with the best clay blocks previously tested. The block was eaten away at the glass line to a depth of 1¼ inches. A few small pits developed in the face and one fairly large oblique crack, which was further enlarged by glass attack.

V. DISCUSSION OF RESULTS

Any attempt to make direct comparisons between blocks used in different tanks or even in the same tank is not justified. A review of the photographs of the blocks after use shows at once that blocks in different positions in the same tank were not exposed to the same corrosive action. In general, the bridge wall received the most severe treatment. Blocks in the melting chamber were exposed to much more severe conditions than those in the refining chamber, and of the former the end-wall position was the worst. Next in order are the side-wall blocks nearest the end wall and then the side-wall blocks nearest the bridge.

Table 1 is useful in estimating the relative severity of conditions in the different tanks. It is evident that conditions were not the same in all the tanks, and that consequently a block from one tank can not always be compared with a block from any other tank even though

the blocks occupied the same positions. However, the table shows that tanks 5 and 6 are comparable in operating conditions as are tanks 2, 8, and 9. Tank 4 had the most severe treatment.

TABLE 1

Tank No.	Duration of test	Average temperature in arch	Batch melted	Tank No.	Duration of test	Average temperature in arch	Batch melted
	Days	°C.	*Pounds*		*Days*	°C.	*Pounds*
2	34	1,450	9,000	6	36	1,500	12,000
3	26	1,525	9,000	7	37	1,450	12,000
4	36	1,525	13,000	8	27	1,450	11,000
5	35	1,525	11,000	9	38	1,425	12,000

Chemical analyses and absorption determinations were made on most of the blocks used (Table 2), but in general there appears to be little relation between either chemical composition or porosity and resistance to glass attack. The effect of homogeneity of a refractory on its resistance to glass must be considerable, and as yet no satisfactory means of measuring homogeneity has been devised. Many instances of distintegration of tank blocks by pitting are shown in the photographs. Such pitting may be the result of (1) the presence of numerous coarse pores in the block, (2) a decided difference in composition between grog and bond, or (3) lack of adherence between the particles in the refractory. To be able to determine by physical and chemical tests alone the resistance of a refractory to glass action, suitable methods of measuring the properties enumerated above must be devised, and the relative importance of these properties in providing resistance to the action of molten glass must be determined.

TABLE 2

Tank No.	Block No.	Chemical composition						Absorption		Softening point
		Ignition loss	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Sum	Total	After 5 minutes [1]	
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Cones*
	9A	0.37	59.60	35.46	1.72	2.01	99.16	11.6	60.2	30
	1B	.18	70.36	25.40	1.82	1.56	99.32	12.6	53.4	28
	10B	.20	61.34	34.05	1.69	2.08	99.36	10.9	54.6	29–30
	10A	.20	61.34	34.05	1.69	2.08	99.36	10.9	54.6	29–30
	1A [2]							11.5	55.8	29–30
	9B [3]							11.6	60.2	30
	BS [4]									
	Block (bridge) [4]									
	11A [5]	.30	62.30	33.01	1.49	2.06	99.16	14.4	75.7	30
	1-L	.34	57.66	37.37	1.85	1.92	99.14	9.2	54.5	32
2	3-K	.30	63.50	31.37	1.91	1.88	98.96	11.4	65.4	28
	3-E	.14	64.24	31.02	1.92	1.88	99.20	14.1	76.0	27
	1-I	.32	57.38	37.35	1.79	1.90	98.74	13.0	70.9	32
	Bridge [4]									
	2F	.30	73.16	23.17	1.03	1.56	99.22	11.5	67.0	27
	2J	1.48	70.60	24.18	1.48	1.60	99.34	12.8	52.1	27
	3A	.14	64.24	31.02	1.92	1.88	99.20	14.6	66.6	27
3	3F	.30	63.50	31.37	1.91	1.88	98.96	12.6	68.7	28
	2B	.34	65.06	29.67	2.05	1.80	98.92	15.5	67.5	29
	10F [3]									
	30A	.34	57.66	37.37	1.85	1.92	99.14	14.2	67.4	32
	2B	.34	65.06	29.67	2.05	1.80	98.92	11.2	69.2	29
	y	.18	70.36	25.40	1.82	1.56	99.32	11.5	55.8	28
4	2D	.36	56.44	37.88	1.80	1.96	98.44	12.6	53.5	32
	2B	.34	65.06	29.67	2.05	1.80	98.92	15.5	67.5	29
	2F	.30	73.16	23.17	1.03	1.56	99.22	11.5	70.0	27
	5B [4]									
	1H	.14	64.24	31.02	1.92	1.88	99.20	13.0	51.5	27
	3B	.14	64.24	31.02	1.92	1.88	99.20	13.0	51.5	27
	GP	.35	56.63	38.81	.27	1.80	97.86	15.1	53.5	33
	8A	.34	64.22	31.03	2.46	1.63	99.68	14.9	58.3	30+
	BS30	.34	57.66	37.37	1.85	1.92	99.14	4.7	51.0	32
5	2C	.31	63.37	32.11	1.11	1.87	98.77	14.8	54.5	29
	BS30	.32	57.38	37.35	1.79	1.90	98.74	4.7	51.0	32
	3B	.14	64.24	31.02	1.92	1.88	99.20	9.5	71.2	27
	1D	.18	70.36	25.40	1.82	1.56	99.32	14.1	64.5	28
	1G	.34	57.66	37.37	1.85	1.92	99.14	12.5	57.5	32
	1H	.32	57.38	37.35	1.79	1.90	98.74	12.9	58.2	32
	RAC							11.0	79.0	
	RSC							9.7	67.7	
6	3E	.14	64.24	31.02	1.92	1.88	99.20	14.2	68.1	27
	1E	.18	70.36	25.40	1.82	1.56	99.32	14.5	63.1	28
	3C	.14	64.24	31.02	1.92	1.88	99.20	13.6	54.0	27
	MA [4]									
	B57	.18	70.36	25.40	1.82	1.56	99.32	12.6	50.7	28
	RAF	.32	9.34	89.16	.25	.50	99.57	7.6	62.7	
	RSF	.26	29.52	68.94	.45	.32	99.49	15.2	74.4	
7	GA-2	.21	53.43	43.76	.79	1.47	99.66	16.8	67.2	
	M-55 [4]									
	GA-1 [4]									
	L-30 [4]									
8 [4]										
9	A	No data on chemical composition						14.6	89.1	
	B							13.7	87.6	
	C							12.0	91.7	
	D							10.7	89.7	
	E							(6)	(6)	
	F							(6)	(6)	
	G							4.2	95.2	

[1] Expressed as percentage of total absorption.
[2] Analysis same as 1B.
[3] Analysis same as 9A.
[4] No data.
[5] Same as 10B.
[6] Negligible.

WASHINGTON, September 12, 1928.